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PREFACE TO THE FIRST EDITION.

WITHIN the last quarter of a century the rudiments of education have been attained by a vast body of the people; these tools of knowledge, being therefore at their command, should be employed in rearing up that mental edifice, perishable only with life, which ennobles the possessor, and by its utility gives world-wide fame to a community.

Science was for a long period clad in antiquated and technical phraseology, causing it to be difficult and repulsive to the popular mind, and requiring for its attainment a greater degree of preparatory study than was within the power of many to obtain. Thus the beauty and simplicity of the laws of nature remained a sealed book to the majority of readers; and the writers on the subject had to charge a high price for their works in consequence of the limited demand for them.

Some years ago Dr. Arnott issued his able work 'The Elements of Physics;' in which almost all difficult and learned terms were discarded, and the sciences unfolded in all the beautiful simplicity of their nature, adorned only by poetic language called forth by the sublimity of the subject. This work has been long out of print; while its high price rendered it accessible only to the few. Since

its publication, science has made gigantic strides, and every day reveals some new wonder or important application.

We have ventured on the same path as the learned Doctor, with the advantage of having had him for a predecessor, and trust we have produced a useful work. In pursuance of this object, every pains has been taken to give such illustrations as may enable the eye to convey to the mind what would else be difficult of comprehension.

It will be seen that the subjects of Natural Philosophy are often as intensely exciting as a powerfully-drawn romance; with this difference, that the passions are not wrought upon, but the moral feelings aroused, the pleasure of life increased, and our reverence, awe, and love of the Creator deepened by a knowledge of the phenomena with which nature surrounds us. The Prince Consort, in a recent address, has given an epitome of the utility and importance of Natural Philosophy. "Man," observes the noble and enlightened Prince, "is approaching a more complete fulfilment of that great and sacred mission which he has to perform in this world. His reason being created after the image of God, he has to use it to discover the laws by which the Almighty governs his creation, and by making these laws his standard of action, to conquer Nature to his use—himself a Divine instrument. Science discovers these laws of power, motion, and transformation; industry applies them to the raw material which the earth yields us in abundance, but which becomes valuable only by knowledge."

To aid the progress of our countrymen to the highest mental condition, to fertilise the seeds of genius, to pro-

mote sound education, to give that elevating tone to the popular mind so productive of happiness, to implant a love of knowledge in the rising generation, and a full appreciation of the wonders of the works of God, has been the desire and the aim of

JABEZ HOGG.

June, 1853.

PREFACE TO THE SECOND EDITION.

It is unnecessary to say more about the plan and purport of this Elementary Treatise, the sale of an edition of ten thousand copies having made it well known, and given sufficient evidence of public approval; it will suffice therefore if I briefly state in what this Second Edition differs from the former.

In the first place, it has been deemed advisable by my publisher to change the form and size, and thus make it uniform with the many valuable works he has issued to the public from time to time, and which enjoy a world-wide reputation: in so doing he has added considerably to the number of pages, and inserted numerous new engravings. Besides this, the whole of the text has received a careful revision, and much new matter has been everywhere incorporated, with the view of bringing the present edition down to the knowledge and discoveries of the day, so as to render it more acceptable to the student and the public. J. H.

June, 1861.

INTRODUCTION.

If we examine the mere signification of the two words Natural Philosophy, we find that natural means something that is produced by nature; and philosophy, from the Greek, is literally "love of wisdom or knowledge." Thus, then, the words imply love of a knowledge of the productions of nature or God. Knowledge, in its true sense, is an accumulation of facts; these man carefully collects, and reasoning thereupon, is capable of penetrating many of the secret workings of nature, and turning such acquisition to his peculiar advantage. Natural Philosophy is also termed Physics; that is, a study of nature by means of the strictest modes of investigation the intellect of man has at command.

Man cannot form any of the materials of nature; but by a knowledge of their properties he may shape them to his own use, which is called Art. He must have studied the peculiar quality of iron-stone before he knew the treasure it contained; the effect of heat upon it he must have tried before he could fabricate the rough chisel to rend from the quarry and fashion the stone under which he found shelter. The iron and stone are the productions of nature; the chisel, the form of the stone, and the house, are the efforts of art.

Wide is the scope of Natural Philosophy. It leads to an acquaintance with the laws that keep the planets in their undeviating path; it treats of the phenomena of the earth, the air, and the ocean; of the simple principles of mechanism that man employs; of the falling of the silent dew or the rushing of the roaring cataract; of the heat of summer and the frost of winter; of the zephyr-breeze or the destructive tornado; of the swimming of fishes or the flying of birds; of

the ripple of the placid lake or the mountain waves of the ocean; of the grace, motion, and powers of the human form; of the mechanism of the voice, the ear, and the eye.

By an acquaintance with its first principles—the embellishments of a palace, the necessities of a cottage, the swinging of a carriage, and the management of a dray, are all better accomplished. The elasticity of air and steam, that drives the vessel despite of tide or wind, or sends tons of merchandize with surprising velocity to the extremes of a kingdom, are by its teaching comprehended. Knowing the cause of the awful voice of thunder, of the terrific destruction of lightning, and of the peaceful beauties of the rainbow, much ignorant teaching is dispelled. Man has so advanced in his comprehension of nature, that he chains one of the most fearful elements to his use, which he guides and directs as if it were possessed of the feebleness of a helpless babe; with it he sends his thoughts with a speed surpassing the rapid flight of time. No one can feel but abashed at not understanding the simple principles that produce such seemingly miraculous effects.

It is the duty of the natural philosopher, and the student in physics, to ascertain the nature and causes of the mysterious phenomena by which we are surrounded. Ultimate causes are certainly beyond our powers of analysis; we may approximate to a knowledge of some of them, but we cannot ascertain their nature, or the actual extent of their influence. Nearly all the appearances in nature may be resolved into the production of motion; and we are able to ascertain its laws, but cannot discover its origin.

The most important progress in Natural Philosophy by which the present century is distinguished, has been the discovery of a general law which embraces and rules all the various branches of physics and chemistry. This law is of as much importance for the highest speculations on the nature of forces, as for immediate and practical questions in the construction of machines. This law is now known by the name

of "the principle of conservation of force." It might be better perhaps to call it, with Mr. Rankine, "the conservation of energy," because it does not relate to that which we call commonly *intensity of force.* It does not mean that the intensity of the natural force is constant; but it relates more to the whole amount of power which can be gained by any natural process, and by which a certain amount of work can be done. For example: if we apply this law to gravity, it does not mean, what is strictly and undoubtedly true, that the intensity of the gravity of any given body is the same as often as the body is brought back to the same distance from the centre of the earth. Or with regard to the other elementary forces of nature, *chemical force*: when two chemical elements come together, so that they influence each other either from a distance or by immediate contact, they will always exert the same force upon each other—the same force both in intensity, and in its direction, and in its quantity. This other law, indeed, is true; but it is not the same as the principle of conservation of force. We may express the meaning of the law of conservation of force by saying, that every force of nature, when it effects any alteration, loses and exhausts its faculty to effect the same alteration a second time. But while, by every alteration in nature, that force which has been the cause of this alteration is exhausted, there is always another force which gains as much power of producing new alterations in nature as the first has lost. Although, therefore, it is the nature of all inorganic forces to become exhausted by their own working, the power of the whole system in which these alterations take place, is neither exhausted nor increased in quantity, but only changed in form. Some special examples will enable us better to understand this law than any general theories. To begin with gravity,—that most general force, which not only exerts its influence over the whole universe, but which at the same time supplies the motive power to a very large number of our machines. Clocks and smaller

machines are generally set in motion by a weight. The same is really the case with water-mills. Water-mills are driven by falling water, and it is the gravity, the weight of the falling water, which moves the mill. Now by water-mills, or by a falling weight, any machine can be put in motion; and by such motive power every sort of work can be done which can be done at all by any machine. Therefore the weight of a heavy body, either solid or fluid, which descends from a higher place to a lower place is a motive power, and can do every sort of mechanical work. But if the weight has fallen down to the earth, then it has the same amount of gravity, the same intensity of gravity; and its power to move, its power to work, is exhausted; it must become again raised before it can work anew. In this sense, therefore, the faculty of producing a new work is exhausted—is lost; and this holds true of every power of nature, when this power has once produced alteration.

Hence therefore the faculty of producing work, of doing work, does not depend upon the intensity of gravity. The intensity of gravity may be the same, the weight may be in a higher position or in a lower position, but the power to work may be quite different. The power of a weight to work, or the amount of work which can be produced by a weight, is measured by the product of the height to which it is raised, and the weight itself. Therefore our common measure is *foot-pound*, that is, the product of the number of feet and the number of pounds. Again, we can by the force of a falling weight raise another weight; as, for example, the falling water in a water-mill may raise the weight of a hammer. Therefore it can be shown that the work of the raised hammer, expressed in foot-pounds, that is, the weight of the hammer multiplied by the height expressed in feet to which it is raised,—that this amount of work cannot be greater than the product of the weight of water which is falling down, and the height from which it fell down. We have yet another form

of mechanical motive power, that is, *velocity*. The velocity of any body in this sense, if it is producing work, is called *vis viva*, or the living force, of that body. Take a rifle ball as an example. When shot off it acquires great velocity, and has immense destructive power; as soon as it has lost its velocity, it is once more a harmless thing. The great power it has depends only on its velocity. In the same sense, the velocity of the air, the velocity of the wind, is a motive power; for it can drive windmills, and by the machinery of the windmills it can do every kind of mechanical work. This proves to us that velocity in itself is a motive force.

Take a pendulum which swings to and fro. If the pendulum be raised to the side, the weight is raised up; it is a little higher than when it hangs perpendicularly. Now if we let it fall, and it comes to its position of equilibrium, it has gained a certain velocity. Therefore, at first, we had motive power in the form of a raised weight. If the pendulum comes again to the position of equilibrium, we have motive power in the form of *vis viva*, in the form of velocity, and then the pendulum goes again to the other side, and it ascends again till it loses its velocity; then, again, *vis viva* or velocity is changed into elevation of the weight; thus we see in every pendulum that the power of a raised weight can be changed into velocity, and velocity into the power of a raised weight. These two are equivalent.

Again, take the elasticity of a bent spring. It can do work, it can move machines, watches. The cross-bow contains such a spring. These springs of the watch and cross-bow are bent by the force of the human arm, and they become in that way reservoirs of mechanical power. The mechanical power which is communicated to them by the force of the human arm, afterwards is given out by a watch during the next day. It is spent by degrees to overpower the friction of the wheels. By the cross-bow, the power is spent suddenly. If the instrument is shot off, the whole amount of force which is commu-

nicated to the spring is then again communicated to the shaft, and gives it great power.

Now the elasticity of air can be a motive power in the same way as the elasticity of solid bodies; if air is compressed, it can move other bodies: let us take the air-gun; there the case is the same as with the cross-bow. The air is compressed by the force of the human arm; it becomes a reservoir of mechanical power; and if it is shot off, the power is communicated to the ball in the form of *vis viva*, and the ball has afterwards the same mechanical power as is communicated to the ball of a gun loaded with powder.

The elasticity of compressed gases is also the motive power of the mightiest of our engines, the steam-engine; but there the case is different. The machinery is moved by the force of the compressed vapours, but the vapours are not compressed by the force of the human arm, as in the case of the compressed air-gun: the compressed vapours are produced immediately in the interior of the boiler by the heat which is communicated to the boiler from the fuel. Therefore in this case the heat comes in the place of the force of the human arm, so that we learn by this example, that heat is also a motive power. This part of the subject, the equivalence of heat as a motive power, with mechanical power, has been that branch which has excited the greatest interest, and has been the subject of deep research. It may be considered as proved, that if heat produces mechanical power, that is, mechanical work, a certain amount of heat is always lost. On the other hand, heat can be also produced by mechanical power; namely, by friction and the concussion of unelastic bodies. You can bring a piece of iron into a high temperature, so that it becomes glowing and luminous, by only beating it continuously with a hammer. Now, if mechanical power is produced by heat, we always find that a certain amount of heat is lost, and this is proportional to the quantity of mechanical work produced by that heat. We measure mechanical work by foot-pounds, and the amount

of heat we measure by the quantity of heat which is necessary to raise the temperature of one pound of water by one degree, taking the Centigrade scale. The equivalent of heat has been determined by Mr. Joule, of Manchester. He found that one unit of heat, or that quantity of heat which is necessary for raising the temperature of a pound of water one degree Centigrade, is equivalent to the mechanical work by which the same mass of water is raised to 423½ metres, or 1389 English feet. This, then, is the mechanical equivalent of heat.

Hence, if we produce so much heat as is necessary for raising the temperature of one pound of water by one degree, then we must apply an amount of mechanical work equal to raising one pound of water 1389 English feet, and lose it for gaining that heat.

By these considerations it is proved that heat cannot be a ponderable matter, but that it must be a motive power, because it is converted into motion or into mechanical power, and can be either produced by motion or mechanical power. Now, in the steam-engine we find that heat is the originator of the motive power, but the heat is produced by burning fuel, and therefore the origin of the motive power is to be found in the fuel; that is, in the chemical forces of the fuel, and in the oxygen with which the fuel combines.

From this we find that chemical forces can produce mechanical work, and can be measured by the same units and by the same measures as any other mechanical force. We may consider the chemical forces as attractions, in this instance, as attraction of the carbon of the fuel for the oxygen of the air; and if this attraction unite the two bodies, it produces mechanical work just in the same way as the earth produces work, if it attract a heavy body. Now the *conservation of force*, of chemical force, is of great importance, and it may be expressed in this way. If we have any quantity of chemical materials, and if we cause them to pass from one state into a second state, in any way, so that the amount of the materials

at the beginning, and the amount of the materials at the end of this process be the same, then we have always the same amount of work, of mechanical work, or its equivalent, done during this process. Neither more nor less work can be done by the process.

Commonly, no mechanical work in the ordinary sense is done by chemical force, but usually it produces only heat; hence the amount of heat produced by any chemical process must be independent of the way in which that chemical process goes on. The way may be determined by the will of the experimenter as he likes.

"We see, therefore," writes Professor Helmholtz, "that the energy of every force in nature can be measured by the same measure, by foot-pounds, and that the energy of the whole system of bodies which are not under the influence of any exterior body must be constant; that it cannot be lessened or increased by any change. Now the whole universe represents such a system of bodies endowed with different sorts of forces and of energy, and therefore we conclude from such facts that the amount of working power, or the amount of energy on the whole system of the universe, must remain the same, quite steady and unalterable, whatever changes may go on in the universe."

Again, in the words of Professor Thomson, "We can now look on space as full. We know that light is propagated like sound, through pressure and motion. We know that there is no substance of caloric—that inscrutably minute motions cause the expansion which the thermometer marks, and stimulates our sensations of heat—that fire is not laid up in coal more than in a Leyden jar: there is potential fire in each. If electric force depends on a residual surface action, a resultant of an inner tension, experienced by the insulating medium, we can conceive that electricity itself is to be understood, as not an accident, but an essence of matter. Whatever electricity is, it seems quite certain that electricity in

motion is heat; and that a certain alignment of axes of revolution in this motion is magnetism. Faraday's magneto-optic experiment makes this not a hypothesis, but a demonstrated conclusion. Thus Foucault's gyroscope finds the earth's axis of palpable rotation; and the magnetic needle shows that more subtle rotatory movement in matter of the earth, which we call terrestrial magnetism, all by one and the same dynamical action."

Many of the facts here lightly spoken of will necessarily come under consideration in the pages of this work, but to promote inquiry and lead the reader to a fuller and deeper acquaintance with the physical sciences, we enumerate a few of the more important works, all of which indeed should be read by any one who desires to make himself thoroughly acquainted with the advanced state of scientific research in the present day: Newton's Principia and Natural Philosophy, and Dr. Young's Natural Philosophy, books which should be studied by all; Peschel's Elements of Physics, translated by West; Ferguson's Mechanics, by Sir D. Brewster; Rankine's Applied Mechanics; and the Encyclopædia Metropolitana.

Among continental authors, the works of Pouillet, Poisson, Biot, and Quetelet, will repay any amount of time and trouble bestowed on them.

The laws of Statics and Dynamics are treated of mathematically in Wood's Mechanics, edited by Snowball; Whewell's Mechanics and Dynamics; Earnshaw's Statics and Dynamics; Wilson's Dynamics; Moseley's Mechanics, and Mechanical Principles and Engineering; and Willis's Principles of Mechanics. The whole subject of Fluid Mechanics will be found treated of mathematically in Miller's Hydrostatics and Hydrodynamics; Moseley's Hydrostatics, and Pratt's Mechanical Philosophy; and the many papers of Young, Gregory, Playfair, &c. in the several Cyclopædias.

In Acoustics, the student is recommended to refer to the

article on Sound, in the Cyclopædia Metropolitana, by Sir John Herschel; also to the works of Chladni, Savart, and Weber.

In Optics, to Sir J. Herschel's Treatise on Light, in the Cyclopædia Metropolitana; Sir D. Brewster's Optics; and Dr. Young's Natural Philosophy; and for fuller information on Polarized Light, to Baden Powell's edition of Dr. Pereira's Lectures; the Philosophical Transactions; and Mr. Griffin's investigations of the laws of double refraction.

In Photography, to Hunt's Treatise, and Hardwich's Manual of Photographic Chemistry.

In Heat, the article in the Cyclopædia Metropolitana, and the papers of Melloni, Forbes, Joule, and Professor Helmholtz.

In Electricity and Galvanism, the works of Faraday, Becquerel, Pouillet, Coulomb, De la Rive, Daniell, and Noad's Manual.

In Organic Electricity and Animal Magnetism, Müller's Physiology, Tiedeman's Traité complet de Physiologie, and Dr. Golding Bird's Lectures; besides which many valuable papers will be found scattered throughout the Philosophical Transactions.

ELEMENTS

OF

NATURAL PHILOSOPHY.

CHAPTER I.

MATTER AND ITS PROPERTIES.

Nature of Matter.

THE earth and the whole universe is composed of matter. It is very difficult to give a correct philosophic definition of matter; but it may be said to include everything which occupies space, which offers resistance to the touch, or which can be weighed. All these three properties may be discovered in every variety of solid, of liquid, and of air or gas. Solids, liquids, and gases are alike material, but differ from one another in the manner in which their particles are arranged. In solids these particles are close to one another, and adhere to form a mass, more or less firm. In liquids the particles are close, but do not adhere to form a mass. In gases the particles are at some distance from each other, and float about in all directions.

Scientific men at the present day have very generally come to the conclusion that all bodies are composed of a number of infinitely small particles, called atoms, or molecules. This is rendered probable by a number of facts in chemistry, but cannot certainly be proved, inasmuch as these atoms must be of a size which places them altogether beyond human ken,—in fact, of a smallness so extreme that it can hardly be expressed by arithmetic. This we know by the manner in which all known

bodies admit of being divided or reduced to smaller parts, whereas the nature of atoms is such that they are indivisible and impenetrable, always of the very same weight, size, and shape.

In definite chemical bodies, as water, salt, and sugar, each atom is a compound one, made of a bundle of still simpler atoms,—as in water, of oxygen and hydrogen; in salt, of chlorine and sodium. These four substances are called simple. Each is made of atoms which are all the same, but differ from those of every other body. So is salt or sugar made of atoms which are all the same in each, but they are compound atoms, as just stated. Each compound atom contains the simple atoms firmly and chemically united.

But many bodies that we see, such as wood or flesh, are still more heterogeneous in their structure. Thus wood contains lignine, starch, sugar, resin, and water—each of these a chemical substance made of compound atoms; but these are all mixed together in wood, and not united firmly, or in a regular way. Such is the theory generally received as to the nature of material bodies.

Indestructibility.

As far as we know, matter can never cease to be. The atoms of which it is composed are absolutely indestructible. A solid body may be transformed into a liquid, or a liquid into a vapour, by the agency of heat, but it is not therefore destroyed. A piece of rock may be disintegrated, and apparently destroyed by the action of an acid, but it is only decomposed into the two parts of which it always consisted: one part passes as a gas into the air, the other remains behind and unites with the acid. Organic substances, as the bodies of plants and animals, when they decay, or wood and coal, when burned in the fire, are by no means destroyed. They are decomposed, and their atoms or elements are rearranged, forming vapours and gases which pass into the air around us. Thus nothing is ever lost in the universe.

A perpetual round of change is always going on in the material world, the whole of which is a system of death and reproduction. Both plants and animals exhale, while living, peculiar gases into the air. That which plants exhale (oxygen) is breathed by animals, that which animals exhale

(carbonic acid) is breathed by plants: nor is this all. Out of earth and air plants are able to construct food. Upon this animals live. They, when they die, turn again to earth and air, upon which plants live. Thus, of matter, there is never less, never more, though it is always in a state of transition.

Divisibility.

Though we believe the ultimate particles of matter to be impenetrable, yet, so infinitely small are they, that matter may be divided to an apparently unlimited extent.

Gold is a common example of the divisibility of metals. It may be beaten out till it covers a space of 50 square inches, and then divided into two million parts, each visible to the eye. Gold-leaf may be made so thin, that a book of 291,000 leaves will only be one inch in thickness. When gold lace is formed from silver wire, the coating of gold is but a four-millionth part of an inch thick.

The soap-bubble (measured by Newton) is nearly as thin as this, and yet contains but one part of soap to 100 of water. Moreover soap is a complex chemical substance, each atom of which contains some 200 other atoms united into one.

A pound of cotton, which may be made to yield a thread 248 miles in length, is a familiar example of divisibility. But that is not much.

Five grains of Tripoli stone, used in polishing, have been found to contain the skeletons or fossil remains of a thousand million animalcules. Each of these animalcules is seen by the microscope to have been a complex organism, possessed of various textures and parts, perfect in its functions, active in its movements.

Even the minute revelations of the microscope are outdone by the atoms of odorous substances. A grain of musk has perfumed an apartment during twenty years. Odour can only be caused by particles of matter in the air; yet, after this lapse of time, the diminution in weight of the grain of musk could scarcely be estimated.

Resistance.

The particles of matter may be separated, but they are impenetrable, and resist any attempt to lessen their size, or to

occupy the space which they fill. If a body can be lessened in size by mere pressure, it shows that its particles were not close together before. One particle resists the attempt of another to take its place, simply because matter must have place in which to lie. Thus one piece of marble cannot be forced into another, and two take the room of one; if such a thing were possible, the whole world might by degrees be got into a nutshell.

No power whatever will be able to force down the piston of a water-syringe if the orifice be stopped. The water resists compression with a force sufficient to support a mountain, if the syringe were strong enough. Air also, though an elastic fluid, resists compression with some force. If an empty phial be plunged into water with the mouth downwards, it will resist the entrance of the water, on account of the air which it contains.

ATTRACTION.

This word signifies a *drawing towards*. It is a general term applied to all instances of one thing being drawn towards another, by whatever force or power this is done. We now understand it simply of matter, left alone, uninfluenced by external forces. We find that, even so understood, there are several kinds of attraction. By a force of attraction, the particles of a solid, or even a liquid or gas, are held together, and prevented from separating. This force in the particles of one and the same body is called attraction of cohesion. Again, we know that the particles of one body may attract those of another, as when two things stick or adhere together, or when wood is wetted by water, which will not fall entirely from it. This, in two substances often dissimilar, is called attraction of adhesion. And there is, again, another universal and most important kind of attraction, which consists in all bodies drawing towards them, with more or less force, all other bodies. The degree of this force depends upon the mass of the body; when this is very great indeed, other bodies are compelled to approach it. This is called the attraction of gravitation. We shall now speak in turn of these three kinds of attraction.

Attraction of Cohesion.

This is the force which unites particles together into one

body. Even in a gas the particles attract one another to a certain degree; though they are probably at some distance, and are easily separated and divided by any other body without offering resistance (which is the cause that a gas or vapour can scarcely be *felt* by the hand), yet they must hold together, or the gas would occupy an indefinitely large space. In a liquid the particles are drawn into absolute contact by their attraction; yet they are not fixed by it, but roll about freely in all directions. In a solid the attractive force is greater still, being sufficient to bind and fix the atoms into one firm resisting body. The attractive force is greater as the solid is harder. Soft solids, as butter, approach fluids in the weakness of their attraction of cohesion. In deal wood it is stronger, in iron stronger still, and in the hard corundum and diamond strongest of all. Cohesion is overcome when a body is broken; still more when it is powdered, or reduced to the fluid state by heat or other means. Heat strongly favours repulsion, and strives against cohesion. Thus it turns ice into water, and water into steam. When a solid is broken, it is difficult again to promote its natural cohesion, probably because the parts are inflexible, and we cannot produce contact of the atoms. Near contact is necessary for cohesion. To produce this molecular contact, most metals must be melted to join them into a mass. Pieces of iron will unite by *welding*, i. e. being hammered at a white heat. The clean surfaces of a leaden bullet that has been cut in half will unite firmly if they are strongly pressed together. For a similar reason, the very powerful compression of dry clay powder is resorted to by manufacturers to form buttons, tiles, &c. The particles, being brought sufficiently close to exert their force of cohesion, unite into a firm stone.

This approximation is easy in the case of fluids. Two globules of water will at once run together into one, when placed in contact. The same with mercury.

This attraction of cohesion, which binds atom to atom, is to be distinguished from that general attraction which draws all bodies together, which is the attraction of gravitation. The difference to be noted is—cohesion operates only at *insensible distances*, gravitation operates at *all distances*.

Upon the degree and kind of cohesion depends the state of a body, and the various qualities of matter which are now to be spoken of in turn.

Consistence.—The difference between a gas or vapour, a liquid and a solid body, depends upon the degree of approximation of their particles. This approximation is greater the greater the cohesion. Cohesive force is therefore greatest in a solid, least in a gas. Although, comparatively speaking, the atoms of a gas are removed from one another, yet as these atoms are infinitely small, it is probable that the distance between them is also infinitely small. When some gases, such as chlorine, are subjected to great pressure, their particles come in contact, and a liquid is formed. Again, by cold, which promotes cohesion, a liquid may frequently be formed into a solid, its bulk being also in most cases lessened. (Ice, which occupies more bulk than water, is an exception.)

State of Aggregation.—When the particles of matter are aggregated (that is, gathered together) into a solid body, there is generally an opake mass without definite geometrical form, but of any accidental shape determined by circumstances. This is the case with most stones, as chalk or limestone; with rock-alum, and with charcoal. These opake irregular masses of matter are called *amorphous*, that is, destitute of regular form. But nearly all bodies which are simple in nature have an especial tendency to a more regular arrangement of their particles. These may unite in such a manner as to form a mass of a definite geometrical shape, with regular surfaces and sides, as a cube, an octahedron, a prism. These masses are called crystals. Crystals are generally produced when the atoms of a body have time to arrange themselves; thus when a metal is melted and cooled slowly, crystals of the metal may form; or when a soluble substance, as nitre or sugar, is dissolved in water, and the water allowed to evaporate, crystals are deposited. The three substances mentioned above as being frequently met with amorphous, are also capable of assuming the crystalline form. Thus chalk is found crystallized as calcareous spar; if alum be dissolved in hot water, the liquid deposits crystals on cooling; and even black charcoal, which no power of ours can turn into crystals, is found in nature under the beautiful crystalline form of the diamond. Though the crystals of pure metals are opake, most crystalline bodies are transparent, many of them, as the diamond of finest water, destitute of colour.

A well-known and magnificent example of this gem is the

Koh-i-Noor, or Mountain of Light (fig. 1), an Indian diamond now belonging to Her Majesty. Since its public exhibition in the Hyde Park Crystal Palace, it has gained much in splendour by having been recut. This may be understood by a woodcut showing its present appearance.

Fig. 1.—The Koh-i-Noor.

It is not within our province to enter at length into the subject of crystallization. The forms of crystals (fig. 2) are very

Fig. 2.—Forms of Crystals.

numerous and various. The crystalline form of a chemical substance is frequently of help in enabling us to recognize it.

Some bodies, however, as sulphur, have two distinct crystalline forms, and are called dimorphous.

When liquids become solid by cold, they frequently assume the crystalline form. Water freezes into ice, which seems amorphous; but when the vapour of water freezes into frost or snow, it assumes the most beautiful and fantastic geometrical shapes (fig. 3).

Fig. 3.—Snow Crystals.

Amorphous bodies frequently present some appproach to that regular arrangement of parts which characterizes crystals. Some solids, as slate, are *lamellar* in structure, that is arranged in flat plates. Some are *fibrous*, as a rod of iron, or the stem of a plant. Others are *porous*, having minute passages through their substance. This is the case with nearly all bodies, except the hardest crystals and stones.

Density.—The small parts of a body (not the atoms, but masses composed of atoms) may either be closely packed, or loosely arranged together. If close, the body is called *dense*. Snow and wool, which may be squeezed into a very small bulk, are deficient in this property. Wood, and even many metals, may be made to occupy less space by being hammered. Flint is heavier than sand, simply because it is denser. A bottle may be filled with sand, but, as this is loose and porous, it will hold a quantity of water in addition.

Hardness.—A body is *hard* when the cohesion between its atoms is so great that it resists compression or division. The opposite quality is *softness*. Water and air may be cut in any manner, or easily compressed into different shapes. A semi-solid, as butter, offers more resistance. Wood is harder, but may easily be cut or bent. Steel cannot be squeezed, but may still be cut. Glass is harder again; it cannot be cut, without splintering, by any body but one harder than itself, as the

diamond. When bread is cut by a knife, it is because the thin edge insinuates itself between the yielding particles. The atoms of a hard body will not allow their cohesion to be thus overcome.

Brittleness.—This is a peculiar liability in many hard bodies to a sudden derangement of the cohesive force of their atoms by means of a shock or jar. Thus no direct pressure will break glass, if it be supported behind; but a sudden blow, causing rapid vibration amongst its particles, deranges and destroys their cohesion, so that it flies into a thousand pieces. Iron is much softer than glass, that is to say, the cohesion of its atoms is less. Yet iron is far more difficult to break than glass, because its cohesion is not disturbed by a jar, *i. e.* it is not brittle to the extent that glass is.

Tenacity, or *Toughness.*—This is the opposite quality to brittleness. A tough body must possess some degree of hardness, in addition to which it is not easily snapped or broken. A metal like lead is too soft to possess much tenacity. On the other hand, cast iron, which is harder than wrought iron, is less tenacious, on account of its brittleness. Bar-iron may be bent, but not broken; whereas a cast-iron pipe may be chipped with a blow of a hammer. Soft steel is very tough, but the hard tempered edge of a knife is easily notched. The tenacity of metals is estimated by the weight they will bear when made into wire. Steel wire is exceedingly tenacious; when $\frac{1}{10}$th of an inch thick, it will bear 134 lb. The following Table will show the weight that will be supported without breaking by metallic wires of $\frac{1}{10}$th of an inch in thickness:—

Iron . . .	549 lb.	Gold . . .	150 lb.
Copper . .	302 „	Zinc . . .	109 „
Platinum . .	274 „	Tin . . .	34 „
Silver . .	137 „	Lead . . .	27 „

Paper is very tenacious, so is gelatine. The paper of a Bank of England note will bear, when sized, 36 lb.; when stiffened with a grain of size, 56 lb.; or when glued up into a round roll, 1 inch long and 1 inch broad, 30,000 lb., as ascertained by Count Romford. By soaking paper in a weak solution of sulphuric acid, it acquires the toughness or tenacity of parchment.

The gelatine of the skin of animals, when subjected to the process of tanning, becomes tougher than ever, forming leather. The fibres of plants, as cotton, flax, and hemp, are

woven into fabrics of great tenacity. Silk thread, the produce of a worm, equals them in tenacity, and surpasses them in pliability.

The toughness of woods varies much. It is much easier to drive a nail into deal than into oak, and this wood is excelled in hardness and in toughness by that of the beech.

In the construction of ropes and cords, tenacity is the one thing needful. The time-honoured employment of hemp for this purpose is now giving way before the use of iron wire, of which ropes are made of all degrees of thickness, from the cord that supports a telegraph post, to the thick cable of a ship; and from that again to the herculean rope, thousands of tons in weight, which stretches across the Menai to support the enormous tubes of the Britannia Bridge at Conway.

Malleability.—This may be said to be toughness combined with some degree of softness. It is the property possessed by some metals of allowing themselves to be beaten out into thin sheets without breaking. The atoms take up the new position given to them, but still retain their attractive force as before. Gold, which may be beaten into sheets far thinner than tissue paper, possesses this property in a high degree. Brittle metals are not malleable, neither are very hard ones. Iron, when much hammered, may become brittle. It is very malleable when heated to a red heat, in which state it is fashioned by the blows of the smith. Lead, silver, copper, tin, are all malleable to a certain extent.

Ductility.—This is the property of being readily drawn into wire. It might seem akin to malleability, but tin and lead, though malleable, are not ductile. Many hard bodies, when melted, acquire this property. This is especially the case with glass, which, when melted, may be drawn out to any length of hair like fibre. Among metals, platinum, silver, copper, gold, and iron are ductile. To form iron wire, a bar is heated to the melting-point, and their end made sufficiently pointed to pass through a small hole in a piece of steel. The protruded point is seized by a pair of pincers, and the soft metal rapidly pulled through the hole by the workman. Metallic wire may easily be made as fine as the human hair; in fact, of such material the wigs of barristers are now frequently made. The late Dr. Wollaston was enabled to draw platinum wire to the

wonderful tenacity of the three-millionth of an inch in diameter.

Pliability.—This property is possessed by an object which is easily bent without being broken. When a body is bent, one surface is rendered convex, the other concave. If thick, the convex surface is made to measure more in length, the concave less than before. In the first, the atoms must be somewhat separated, in the other surface made nearer. A pliable body must therefore be tough. Yet a very brittle body, as glass, will bend when very thin, as then the separation of the atoms is scarcely appreciable.

Many metals are pliable. The fibres of vegetable and animal bodies are still more so.

Elasticity.—When a bent or compressed body returns to its original position as soon as the force which coerced it is withdrawn, it is called elastic. Both attraction and repulsion are called into play by the exertion of elastic force,—attraction, when the separated atoms of a bent or stretched substance tend again to approach one another; repulsion, when the particles of a compressed body tend again to separate to the same distance as before. Gases and liquids are more elastic than solids. A gas compressed into a confined space will expand immediately when the compressing force is withdrawn. Liquids also are elastic, as may be seen by the force with which water rebounds when projected against a solid body.

Soft solids are commonly unelastic and may be compressed or bent in any manner without reaction. Yet india-rubber, which is soft, is elastic, though not perfectly so, for a piece which is stretched does not return exactly to the same length as before. Lead possesses but little elasticity. Steel and gold are highly elastic. Glass, which is not very pliable on account of its brittleness, is almost perfectly elastic. This assertion may seem strange to those who have fallen into the common error of confounding elasticity with extensibility, and therefore suppose that an elastic body is one which can be stretched. Glass, in its ordinary state, is almost inextensible, but it is said to be perfectly elastic, because a thin piece which has been kept bent for a long time will at once return to its original position when the restraining force is withdrawn.

A hard elastic body, subjected to a sudden compressing force, and as suddenly released from it, is apt to rebound from the

point of compression by the recoil of its particles due to its elasticity. The difference between an elastic and an unelastic substance may be shown by throwing two round balls, one of putty, the other of ivory, against a freshly blackened floor. The soft putty is flattened and sticks to the floor without any attempt at recoil. The ivory ball rebounds, and may be caught in the hand. A small black circle at the part where it touched the floor is a proof of the compression of its particles, for, if they had not been compressed, only a black point would be seen. [A sphere can touch a flat surface at one point only at a time.] The spherical shape of the ball, still perfect, is a proof of the elasticity which caused the rebound.

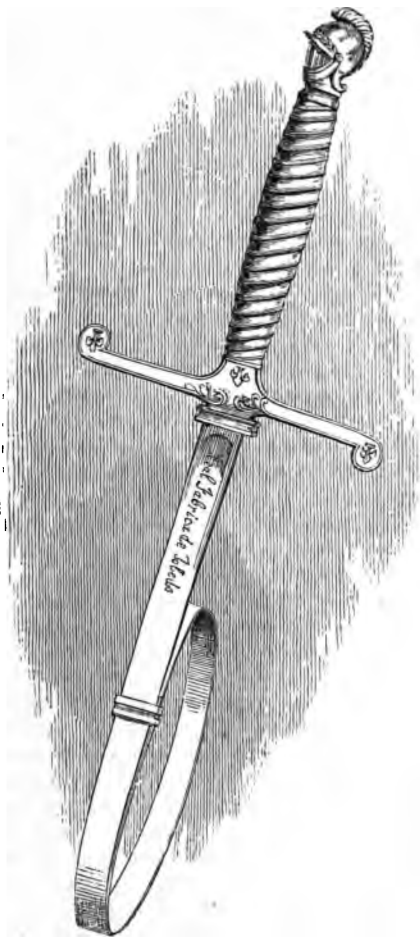


Fig. 4.—Toledo Sword-blade.

For many manufactures and appliances with which we are familiar, we are indebted to this elastic property of bodies.

To the elasticity of iron we are indebted for the luxury of a carriage spring. The far more delicate spring of a watch is made of steel. A sword blade, which may be bent into a circle without breaking, and becomes straight as soon as released, is an example of the elasticity of steel (fig. 4).

To the vibration of metal, caused by its elasticity, the beautiful tone of a bell is owing. In the pianoforte and violin, the elastic vibrations of catgut strings and of wood are also taken into account. In wind instruments, air and metal, both elastic, combine to produce the sound.

To the elasticity of gaseous bodies we owe the power of steam, and the death-dealing force of a gun to the gases suddenly produced by the ignition of gunpowder. Being suddenly produced in a confined space, these gases are in such a state of compression, that, acting upon the point of least resistance, they blow the bullet before them.

Among animal products, hair and feathers are both highly elastic, for which reason they are admirably well adapted to form stuffing for cushions and pillows.

Attraction of Adhesion.

This is the attraction of one body for another when both are placed in contact. Like cohesion, as attraction between atoms, it only operates at insensible distances. Two bodies which attract one another in this way are said to *adhere*, or stick together. As a general rule, one of them must be more or less fluid before this can take place. Water has an adhesive attraction for wood, but not for resin. When a piece of wood floats on water, the surface of the liquid rises around it by this force of attraction. It has no attraction for resin. When a piece is plunged in it, the water is depressed around it, and does not cling to or wet it. Spirit attracts resin, and readily wets it. Liquids which adhere to solids are commonly called 'sticky.' By means of gum, glue, or cement, two solids may be firmly and permanently united together.

Capillary Attraction is a variety of adhesion. It is the force by which water and other fluids tend to rise in small tubes. The name 'capillary' is derived from the Latin word for *hair*, and refers to the fineness of the tubes. In a tube of wide bore, plunged vertically in water, the fluid remains at the same level inside as outside. But in a very narrow tube the water

rises. This is by virtue of two separate forces or attractions. The one is the attraction of the water for the side of the tube, the other the mutual cohesion of the particles of water, enabling them to support one another. Mercury will not rise spontaneously in a glass tube, because it is repelled by the glass instead of attracted. But water and many other liquids rise quickly, to a height which is greater in proportion as the tube is fine in bore.

All porous bodies draw water into their pores by the same force. A piece of cane placed in water will draw the fluid along its pores. A piece of salt or lump sugar, allowed to touch water at one end, becomes soon wetted throughout. By this power a sponge or a cloth will take up water, blotting-paper absorb ink, and the wick of a lamp draw up the oil to the flame.

Wood, allowed to absorb water, swells with enormous force, so that quarrymen in Germany are accustomed to split slate and rend solid stone, by driving a wedge of wood into a crevice and then throwing water upon it. Millstones, made of the hardest stone which can be procured, are split off in the form of flat disks from a cylinder of the same material, by wetting dry pieces of willow wood, which are first driven by the mallet into horizontal indentations cut at proper distances,—so enormous a force is exerted by a soft wood, when swelling by the action of water drawn by capillary attraction along its pores!

Endosmose and *Exosmose* are terms applied to the passage of fluids through animal membranes. The first word signifies a flowing inwards, the second a flowing outwards; but both are governed by the same laws. Two liquids, being on opposite sides of a piece of bladder or other membrane, will pass slowly through the bladder, unless they have some repulsion for it. That passes fastest which has the greatest attraction for it, being drawn through its pores by virtue of capillary action. This passage takes place faster if the liquid have an attraction for the other liquid on the opposite side of the membrane. It is by such a process of endosmose, that the nutriment taken as food, after being reduced to a liquid state in the stomach, passes through the animal membrane into the blood; and again afterwards from the blood through the coat of the vessel to the various tissues of the body. This form of capillary attraction is thus of immense importance in the processes of animal life.

Fig. 5.

Attraction of Gravitation.

It has already been stated that all bodies attract one another at all distances. This kind of attraction is called gravitation, though it is of one particular instance of it, *i. e.* the attraction of the earth for smaller bodies, that the word is most frequently used. Cohesion and adhesion are forms of attraction which operate only at insensible distances. Gravitation is exerted at all distances, though the less the distance the greater the force. The attraction of masses of matter for one another may be illustrated by two examples.

Two lead balls, which are allowed to hang by separate strings, but near to one another, are found, upon a very exact calculation, to approach slightly, so that the line of each string is not quite perpendicular. Light bodies, as feathers and "blacks," when floating in the air, are attracted perceptibly

towards any solid body which they may approach. Pieces of cork or wood, floating freely on water, are drawn together when they come near. The manner in which planks and driftwood congregate into a mass when floating down a stream has often been remarked.

It is supposed that every atom exerts the same force as every other atom. Bodies that we call heavy contain more atoms than light bodies. Bodies of equal weight exert an equal attraction. A heavier body draws a lighter one towards it, and the heavier it is the greater the power with which it does this. For example. Let a leaden plummet hang by a cord by the side of a mountain (fig. 5) or a tall tower. The line is not quite perpendicular, for the plummet is drawn towards the mountain or the tower; and yet the lead hangs down and stretches the line, because it is attracted by the enormous mass of the earth, which is much greater than the mountain or the tower.

In the same manner the moveable water of the ocean is drawn to and fro by the moon as it moves, producing the phenomena of tides. But the sea does not fly off to the moon, but is kept on the surface of the earth, because the bulk of the earth is much greater.

We are now in a position to understand that fall of the apple which set Newton thinking; we see why all smaller bodies are drawn towards the surface of the earth, so that, if lifted from it, they *fall* unless supported; and we can understand how this attraction of gravitation is the same thing as weight.

Bodies influenced by this force are drawn towards the *centre* of the attracting mass. This explains why, on whatever part of the rounded surface of the globe a man may be, he is equally drawn towards the centre and enabled to walk erect. By this force all things are kept in equilibrium and order. Without it, dire would be the confusion in nature, for matter would then roll about in space unrestrained. And not only in this world, for by the law of gravitation, *i. e.* attraction of lighter by heavier bodies, the whole solar system, and doubtless the entire universe, is kept in order. Attracted by the earth, the moon keeps her appointed place. Attracted by the immense bulk of the sun, both earth and moon, with the other planets and their satellites, revolve ceaselessly round the source of light; and, indeed, they would fly into it, were

they not kept in their orbit by another force, to which allusion will be made presently. For this sublime discovery we are indebted to the genius of Newton. The following general law of gravitation is given by him:—"Every particle of matter is attracted by, or gravitates to, every other particle of matter, with a force inversely proportional to the squares of their distances." The first clause of this law we have already attempted to elucidate. The second requires a brief explanation.

The force of attraction, like many other forces, and like heat and light, spreads in all directions; that is to say, *it radiates.* The lines of force pass outwards from the centre, like the spokes from the axle of a wheel. The greater the distance from the centre, the more the lines of force become separated. The force thus acts more and more weakly as it spreads. It spreads in proportion to the square of the distance. The force diminishes in the same ratio; or, speaking scientifically, *it is inversely as the square of the distance* from its origin.

Light is a radiating force; and this law may be proved of light in a simple manner.

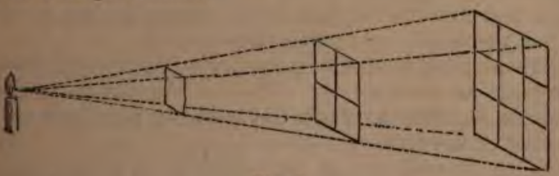


Fig. 6.

Station at the distance of one yard from a candle-flame a board having a surface of 1 square foot; at another yard distance place a board of a surface of 4 square feet; at another yard further off again, a board of 9 square feet superficies. The shadow cast by the first board will exactly cover the second, and that by the second will cover the third. The distance of the first board being 1, that of the second is 2, the square of which is 4, the number of feet of surface; that of the third is 3, the square of which is 9 in like manner.

This shows the progressive separation of the rays. We may next demonstrate, by means of a photometer, that the intensity of the light diminishes in precisely the same proportion.

Suppose the force of gravitation be measured at 1 inch, 1

foot, 1 yard, or 1 mile. At twice the distance it is $\frac{1}{4}$th, at 3 times $\frac{1}{9}$th, at 4 times $\frac{1}{16}$th, at 5 times $\frac{1}{25}$th, decreasing in the ratio of the number given by multiplying the distance into itself.

Thus a falling body is attracted with greater force the nearer it approaches the earth. Thus also the Sun exerts more influence over the planets that are near than those that are far off from it. This tendency is beautifully balanced in our system by the great increase in bulk of the planets that are far off. Venus, Mars, and the Earth, which are near to it, are small in size. Jupiter, Saturn, and Uranus, at a much greater distance, are also very much larger. Jupiter is more than 2000 times larger than Mars; so that the immense weight of this planet compensates for the loss of gravitation incurred by its distance from the Sun. It is supposed also that the attraction of this large mass for the other planets acts as a balance to that of the Sun.

It is by various mathematical calculations founded on the law of gravitation, that the astronomer is enabled to calculate what the weight of a body would be on the surface of any of the planets, or the Sun; he can determine also the quantity of matter contained in the Sun, or any planet having satellites, and find the density of that matter.

Newton stated that the same body would weigh twenty-three times as much on the surface of the Sun as on that of the Earth, but that the Earth had a density four times greater than that of the Sun.

The recent discovery of the planet Neptune has given a striking confirmation of the universal truth of the Newtonian law. It was observed by astronomers that the planet Uranus was subject to some slight deviation from the prescribed course of a certain portion of his orbit. Two astronomers, French and English, Leverrier and Adams, assumed at the same time, as the result of their several calculations, the existence of another large planet, the mass of which, by attracting Uranus, operated as the disturbing cause. They at once pointed out the exact spot of the heavens at which this planet ought to be found at a certain time indicated. To this point telescopes were directed, and Neptune was found.

Weight.—It will now readily be understood that what we call the *weight* of a body is the force with which it gravitates towards the earth. It is supposed that this gravitating force

is in exact proportion to the *real mass*; that is to say, that all atoms are attracted equally by the earth, but in heavy bodies the atoms are closer together than in light ones. We can understand that a sack of feathers contains no more atoms than a lump of lead; but the latter occupies far less bulk for the same weight, because its atoms are close together. The different degree in which equal bulks of matter are attracted constitutes what is called *specific gravity*.

Weight may be estimated by means of a pair of scales. This consists simply of a horizontal beam suspended from the centre. At each end a scale may be hung, keeping the weight on each side equal. Place now in one scale some standard weight, as an ounce or a pound. The weights on each side are now unequal, and the scale on that side will be lowered as much as the beam will permit. Any body to be weighed is now to be placed in the other scale. If it weigh less than a pound, no alteration in the scales will occur, the other scale being drawn towards the earth with the greatest force. If it weigh a pound, equilibrium is exactly restored; both scales gravitate equally, and the beam becomes horizontal. If it be heavier than a pound, the scale opposite the standard weight goes down; and the exact weight of the body may be ascertained by adding smaller weights in the opposite scale until both poise equally.

As all matter is equally attracted, it follows that equal weights of different bodies should fall with equal velocity. But we know that a sack of feathers will not fall so quickly as a lump of lead. This is on account of the resistance offered by the atmosphere, which increases in proportion to the surface of the falling body. This may be proved by the common experiment of the feather and sovereign under the bell glass of the air-pump. In a vacuum (a confined space from which air has been withdrawn), the heavy and the light body fall with equal velocity.

Light bodies tend to rise or float in heavier liquids in obedience to the force of gravitation. The air being heavier than the hydrogen gas in a balloon, is drawn below it by the earth; *i.e.* the balloon rises. Wood being of less gravity than water, floats on the surface when plunged in it; while a leaden bullet will sink, for the opposite reason. But mercury is heavier than lead; and the bullet will float on the surface of that liquid.

Weight in one sense may be said to consist in *pressure.* All gravitating bodies press downwards towards the centre of the attracting mass. The force of this pressure depends upon the weight. Thus a heavy body presses down a light body placed beneath it, and may crush it. By estimating the amount of pressure on the hand, or the muscular exertion required to lift a body, its weight may be roughly ascertained.

It has been shown that the force of gravitation diminishes considerably at a distance from the attracting mass. A body weighed at the level of the sea, weighs less if carried up in a balloon, or taken to a mountain-top; for then it is further off from the centre of the earth. A substance weighing 1000 pounds at the sea-level, loses two pounds of its weight on being carried up a mountain four miles high; but, the scales and weights being equally affected, a balance of a peculiar nature would have to be used to ascertain this loss. It is calculated that, at 1656 miles from the earth's surface, a body would lose half its weight. At the north or south pole a substance is somewhat increased in weight, because nearer to the centre of the earth, which is flattened at the poles. The surface at the latitude of London is nearer to the centre of the earth than at the equator. Thus, if a ship sail full laden from St. Thomas's Island to London, the increase in the weight of her cargo may be such as to cause danger. But at the poles the weight is greater still. These things are not unimportant, but have a bearing on more than one practical matter; among others, on the regulation of the pendulum. It is of paramount importance that this instrument should be always of the same length; but as the weight of the bob varies at different latitudes, it causes the pendulum to be somewhat longer towards the poles than it is near the equator.

Specific gravity.—This is *comparative weight,* that is, the weight of a certain bulk or measure of a body, compared to that of the same bulk of another body. By common consent, distilled water is regarded as the standard of comparison. A pound of lead and a pound of water have, of course, the same weight. But a cubic foot of lead weighs eleven times as much as a cubic foot of water. Water, being the standard of comparison, is unity. Water being 1, sulphur, which is twice as heavy, is 2; marble, $2\frac{1}{2}$ times as heavy, stands 2·5; diamond is 3·5, tin 7·3, iron 7·5, copper 8·7, silver 10·5, lead

11, mercury 13·5, gold 19, platinum 20. Taking the weight of a certain bulk of water, and multiplying it by one of these numbers, we obtain the weight of the same bulk of the body whose specific gravity is indicated by that number. As a cubic foot of water weighs very nearly 1000 ounces, we can roughly estimate the weight of a cubic foot of any solid or liquid by multiplying its specific gravity by 1000.

The mode in which the specific gravity of solids is estimated is simple and ingenious. The ancient philosopher Archimedes is said to have discovered it suddenly when taking a bath one day,—a discovery which caused him great joy, as it enabled him to determine that the gold crown of Hiero, king of Syracuse, had been adulterated with baser metal—a problem that had for some time baffled all his skill.

A solid suspended in water occupies the space of a mass of water equal in bulk to itself. It is buoyed up by the liquid around it with the same force which previously sustained this quantity of water. It is therefore diminished in weight by the weight of its bulk of water. We first weigh a solid in the air. If heavier than water, so that it will sink, we next attach it to one of the pans of a pair of scales, and weigh it when immersed in water, in the manner represented in fig. 7.

Fig. 7.

Subtracting this weight from the former, *the loss represents the weight of an equal bulk of water.* The calculation is now simple. As the weight of this bulk of water is to the weight of the body in air, so is 1 to the specific gravity of the body.

Thus, if a guinea weighs in the air 129 grains, by being immersed in water, it weighs only $121\frac{3}{4}$; divide then the 129 by the lost weight $7\frac{1}{4}$, and the result is nearly 18; thus it is said guinea-gold is nearly eighteen times heavier than water. If the specific gravity were 18 or more, then the gold would be very fine; but if 17, or less, then it would be too much alloyed, and not worth the standard price.

If the solid body be lighter than water (as a piece of cork or wood), it is attached to a heavy body, the weight of which in water is known, and then suspended in the same manner. Subtracting from the result the weight of the heavy body in water, we obtain the weight of the light body in water, and have next to divide its weight in air by that sum.

There are two ways of taking the specific gravity of liquids. The first is very simple. A glass bottle full of water is weighed; and the weight of the empty bottle being subtracted from the result, we have the weight of the water. The same bulk of the liquid is now weighed in like manner; and its weight being divided by the weight of the water, we have its specific gravity. Small stoppered bottles are made, which hold exactly 1000 grains of distilled water. The liquid being weighed in such a one, we have its specific gravity at once without further calculation. It will be found that this bulk of oil of vitriol will weigh 1845 grains; its specific gravity therefore is 1·845. The specific gravity of alcohol is ·794, of ether ·735, of oil of turpentine ·991. These last are thus lighter than water.

Fig. 8.

An instrument called an *areometer* or hydrometer is employed, as saving much trouble. Its usual form is represented in fig. 8. It may be made of glass or metal. Below is a small ball weighted with mercury; connected by a narrow stem with this, a larger ball containing air; above this, again, a hollow sealed tube, containing a graduated scale. This instrument sinks in distilled water to a certain level, which is marked on the scale; if the liquid examined be lighter than water, it sinks proportionally lower; if heavier than water, being then buoyed up with a greater force, it rises higher. So, by remarking the degree on the scale which is

opposite the level of the surface of the liquid, we can ascertain its specific gravity.

The specific gravity of gases is taken in the same manner as that just explained in the case of liquids. Atmospheric air is taken as the standard. A glass vessel full of air is weighed, at the temperature of 60° and ordinary barometric pressure. This vessel is now exhausted by means of an air-pump. It is next filled with the gas on which the experiment is to be made, proper means being taken to exclude air. The vessel is now again weighed; and the weight of the gas may be compared with that of the air weighed before. Hydrogen gas, which is lighter than air (air=1 or 1·000), has a specific gravity of 0·0694; carbonic acid is heavier than air, 1·529.

It may seem a difficult thing to take the specific gravity of the whole mass of the earth itself; yet this has been done in the following manner.

Cavendish first determined, in the most accurate manner, the attraction exerted on a light body by a large mass of lead. The attractive force of the lead was then compared with that of the earth, the bulk of the lead, and that of the earth itself, being known. The specific gravity of the earth, as compared to that of lead, was thus determined. Cavendish arrived at the result that the mean density of the earth was 5·48 times as much as that of water.

Centre of gravity.

Every connected mass of atoms of matter has a certain point about which all the other parts balance or have equilibrium, which point is called the centre of gravity. By this point the mass may be lifted; or if supported on it (that is, the weight counteracted), the mass or body is at rest. This point has always a certain position in any given body; therefore the part may be known about which, in every position, the mass will have equilibrium. It is the only point in the mass, on every side of which the atoms gravitate equally. Hence the principles of mathematical science supply methods in every case to find the centre of gravity.

If we place a stick across a finger, the part where it balances on the finger will be the centre of gravity. In a ring, the centre of gravity does not exist in the ring itself, but in the

centre part, where the particles of which it is constituted would balance.

If we take a painter's palette and let it hang freely by the edge in its longest direction, and then drop a plummet with a line, the centre of gravity will be in the line that touches the surface of the palette, as on this line it will balance (fig. 9). Turn it sideways, let it hang freely, and again drop the plummet and line, so as to form another line in which the palette will balance. Then, as it is found to be in both these lines, the centre of gravity desired to be known is at the point where they cross each other.

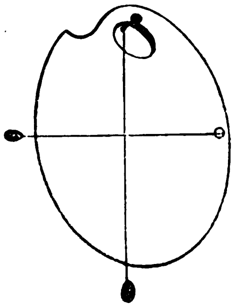


Fig. 9.

To find geometrically the centre of gravity of a triangle, *a c e* (fig. 10), draw a line from *a* to *b*, and from *c* to *d*, bisecting the opposite side; it will balance on either of the two lines, and the centre of gravity is in both the lines, at the point *f*, where they intersect. Moreover, $af = \frac{2}{3}\,ab$, therefore taking a line from one angle bisecting the opposite side, and having measured off from the angular point a distance of two-thirds of its length, we find the centre of gravity of a triangle.

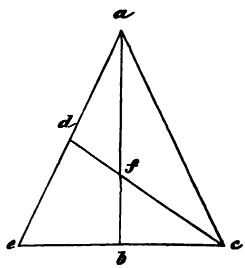


Fig. 10.

Among solid figures it is evident that those will stand most firmly which have the broadest base, as in them the centre of gravity must be low, the lower part outweighing the upper. If we attempt to overturn any substance in the form of a pyramid, we find that its centre of gravity has to be lifted considerably, and also the whole mass of which it is comprised. In fact, according to the breadth of the base of the body, compared with the height of the centre of gravity above it, will be the rise of the centre of gravity—which will be more easily comprehended by the following diagrams. Fig. 11 represents a pyramid, in which, from the breadth of the base, the centre of gravity is low: if this had to be turned over so

as to be supported on the part *s*, the centre of gravity would describe the part of the circle shewn by the dotted line, a circle of which *s* is the centre. The greater the distance that the centre of gravity is from *s*, the greater will be the rise, and the resistance to the lifting force. The line marked by the plummet is called the line of direction of the centre.

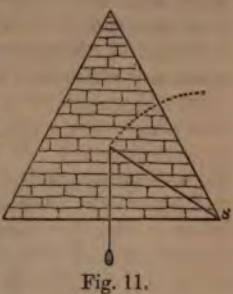


Fig. 11.

In fig. 12 the base is also broad, and therefore firm, from the centre of gravity having to be considerably raised before the body can be overturned.

In figs. 13 & 14, the commencing path of the circle described by the centre of gravity is not so perpendicular as in the former figures; and therefore they are less steady on their bases.

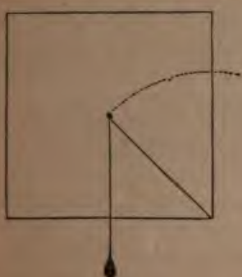


Fig. 12.

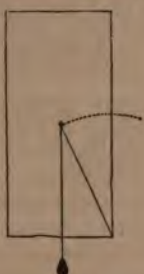


Fig. 13.

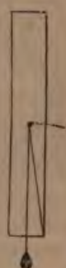


Fig. 14.

In fig. 15, from the narrow base, and the high position of the centre of gravity, the slightest movement would make it fall, as the motion described by the dotted line must be descending.

Fig. 15.

Fig. 16 shows a stable position on one side, and an unstable one on the other; for the sustaining base is actually narrowed: the line of direction falling within the angle formed by a line from the centre of gravity to the corner of the

base, the body is still supported; but if moved over to the right side, the centre of gravity would be lowered, and the body soon fall.

In fig. 17 the line of direction falls beyond the base: its position is unstable; and therefore the object falls.

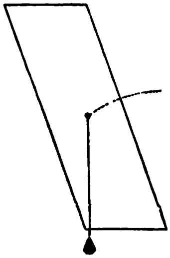


Fig. 16.

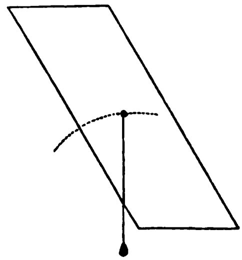


Fig. 17.

Fig. 18 is an oval body, which when on a level plane and moved, the centre of gravity will describe a curve like that of a pendulum, returning to its former position, but not turning over.

Fig. 19 is an oval on one end; and if moved either on one side or the other, as the motion of the centre of gravity is downwards, it will fall.

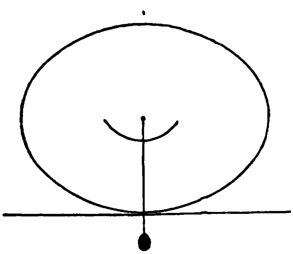


Fig. 18.

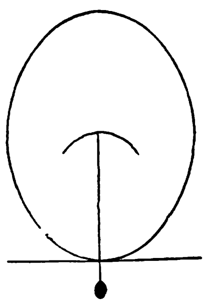


Fig. 19.

A globe or ball (fig. 20), when on a level plane, is supported on a single point; but as in every position the centre of gravity would be at the same distance from the sustaining point,

it has no tendency to move. When it is moved, the centre describes the straight line $a\ b$. The equilibrium in this case receives the term indifferent, as it makes no attempt, on being moved, to return to its former position, or move from that in which we place it.

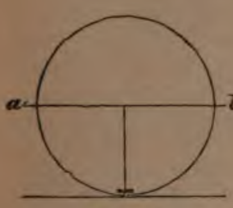


Fig. 20.

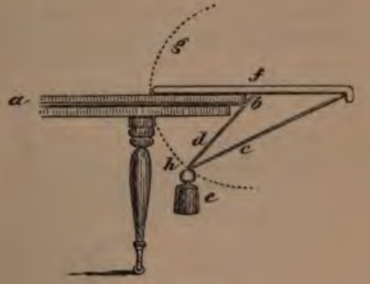


Fig. 21.

Place a walking-stick on the edge of a table $a\ b$ (fig. 21), so that it would fall if left to itself; attach to it a weight e by a cord d; place a rod c against one end of the stick and the top of the weight, which rod must be of such a length as to push the weight a little underneath the edge of the table; and the whole will rest steadily in their positions. The cord being out of the vertical, no lateral motion can be given to the weight without raising the centre of gravity of the system: the stick in falling must turn round the edge of the table; in so doing it will describe the dotted part of a circle g, lifting the centre of gravity in the arc h; now as the weight is heavier than the stick, this is against the laws of gravity; hence equilibrium is preserved.

If a cart or coach be loaded so high that its centre of gravity is at a considerable height from the base, a slight inclination on either side, throwing the line of direction outside the wheels, will cause the vehicle to be overturned.

In the human body the centre of gravity must be directly above the points of support, which are the feet. If, therefore, we take a load on our backs, we bend forwards, so that the centre of gravity may be above the point of support; or in taking a weight in the arms, we lean backwards. If we wish to stand very firmly, we widen the base by placing the

legs at a greater distance and turning out the toes. The walking on wooden legs or stilts requires practice, as it is difficult to preserve an equilibrium in so unstable a position.

Fig. 22.—Leaning Tower at Saragossa.

On looking at the ancient statue of Hercules, the feet are seen turned out, giving an appearance of strength and firmness. In that of Mercury, where swiftness is the object to be personified, the feet are nearly straight, and the toes only touch the ground.

The tower at Saragossa (fig. 22) overhangs its base several feet; but the tenacity of its materials holds it together, and its centre of gravity is preserved.

Fig. 23.—The juggler preserving his centre of gravity.

The London Monument inclines much, as also do several tall church spires. But the broad-based Pyramids of Egypt, of all human monuments the most enduring, hold their position on no such feeble tenure, and seem likely to stand for ever.

Chemical Attraction.

This kind of attraction is quite distinct from those ordinary forces which have just been considered, and is not usually conceived to be within the scope of Natural Philosophy. In ordinary physical attraction the masses of matter drawn together are not altered in nature by the force exerted; but in chemical attraction, two (or more) atoms, or bodies, unite together to form a third substance perfectly distinct from both. The force by reason of which they unite is also called affinity. Two gases—hydrogen and oxygen—unite to form water; a corrosive acid, united with a hard metal and oxygen gas, will form a mild salt. Thus this force is not a simple attraction, but an attraction that results in union, and causes change of nature.

It is found, however, that the atoms of what we call different substances will not cohere and unite indifferently, as atoms of the same kind do, there being singular preferences and dislikes among them, if it may be so expressed; and when atoms of two kinds do combine, the resulting compound generally loses all resemblance to either of the elements. Thus, sulphuric acid will unite with copper, and form a beautiful translucent blue salt; with iron it will form a green salt; and if a piece of iron be thrown into a solution of the copper salt, the acid will immediately let fall the copper, and take up or dissolve the iron. Sulphuric acid will not unite with or dissolve gold at all. Quicksilver and sulphur unite in certain proportions, and form the paint called vermilion; in other proportions they form the black mass called Ethiop's mineral. Lead and oxygen gas from the atmosphere form together what is called red lead, used by painters. Sea-sand, or flint, and the salt called soda, when heated together, unite and form that most useful substance called glass. Certain proportions of sulphur and of iron combine, and produce those beautiful cubes of pyrites, or goldlike metal, which are seen in slate. Chemical attraction, operating thus, does not in the slightest degree interfere with general attraction or gravity; for every chemical compound weighs just as much as its elements taken separately.

Repulsion.

As a property of matter, this is just the opposite to attraction. Attraction is the force by which the atoms of matter are drawn towards each other. Repulsion is a force by means of which they are repelled or driven asunder from one another.

Many cases of so-called repulsion, are simply instances of *diminished attraction*. The particles of gas attract one another; but still they are not close together, and, when compared to the atoms of a liquid or solid, they are said to be in a condition of mutual repulsion. It is apparent that this, though true as a comparative statement, is not strictly the case.

In much the same manner, an absence of adhesive attraction between two different solids, is commonly termed repulsion. The particles of water in a drop of dew have no attraction for the waxen surface of a leaf, or for the oily feather of a duck's back. Their mutual cohesion is thus left to operate undisturbed, and it causes them to gather into the form of a globe. By taking proper care, a fine needle may be floated on the surface of still water, being protected from sinking by a thin coating of grease, which adheres to it, and which has no attraction for the water. Air has an attraction for glass; and barometer-tubes are sometimes spoiled by the air creeping up between the mercury and the tube.

Glass, too, has an attraction for water; but it has none for mercury. If a plate of glass be dipped vertically into water (fig. 24), the liquid will at length rise slightly on each side of the plate, by virtue of its attraction. But if the same glass be plunged in mercury (fig. 25), the reverse is the case.

Fig. 24.

The mercury does not adhere to the glass, and, being left to its own cohesive tendency, is depressed on each side, assuming a curvilinear outline, which is a segment of a circle; for all liquid bodies, left to their own cohesion, tend to the spherical form: this is well seen when any liquid *drops* through the air in small masses. A segment of a small sphere is shown by the surface

of mercury in a glass tube of circular bore (fig. 26). It is

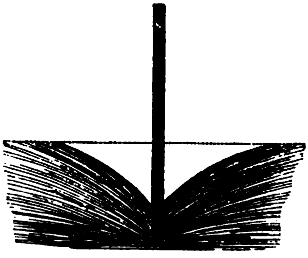


Fig. 25.

Fig. 26.

commonly said that the glass *repels* the mercury: however, it simply has no adhesion for it, and leaves it to its own cohesion. Other instances of such *repulsion* are easily pointed out. Oil has no attraction for water. A glass rod greased will cause the surface of water in which it is dipped to be depressed. If the wires of a fine sieve be oiled, water will not run through it. Mercury will not flow through muslin. If a hand be dusted with *Lycopodium*, it may be dipped in water without being wetted.

Heat, one of the imponderable agents, is a most potent cause of repulsion, or diminished attraction, causing the particles of bodies to become looser in their cohesion, and thus to separate more and more from one another. Thus heat is said to cause repulsion; and cold, which is the absence of heat, favours cohesion. Solid ice, when heated, becomes water, a liquid; water, when further heated, becomes steam, a gas which occupies 1700 times the bulk of the water from which it is formed. Gases, when heated, expand more and more as their particles fly asunder. Matters which expand under the influence of heat, expand *with force*, so as to make it seem probable that the repulsion caused by heat is a real and active repulsion, and not merely the negative of cohesion. Iron expands when heated, and contracts when cold, in both cases with great force; so that the iron beams of buildings and bridges may bring the structure to the ground, if care be not taken to guard against the effect of hot and cold weather. Water, when heated above the boiling-point, will burst any vessel in which it is confined, unless it be of enormous strength.

Or a closed bladder placed before the fire, or tightly corked bottle placed among red-hot coals, will burst by the expansion of the contained air.

Heat, then, is the great cause of repulsion between the particles of matter. Another cause (of repulsion as well as attraction under certain conditions) is electricity. Of these imponderable agents, separate mention will be made in the latter part of this volume.

CHAPTER II.

MOTION AND FORCES.

Motion, &c.

MOTION signifies a change of place; everything is either at rest or in motion.

Motion exists in the heavens and the earth; by it we have day and night, heat and cold, rain and sunshine, tides and tempests, life and sound; in fact, without it, all would be silence, coldness, and death.

Various kinds of motions are to be distinguished:—

Common Motion is that in which we participate with other objects; thus, on the earth's turning on its axis daily, and revolving round the sun annually, we unconsciously move with it; so calmly majestic is this motion, that few think they are on the surface of a body turning round at a rate of nearly one thousand miles an hour, and advancing in a circle, at the same time round the sun with a velocity of 68,040 miles every hour, or nineteen miles every second of their existence.

Thus it is that, when motion is easy and regular, we are insensible of it from partaking of that of the object in or on which we move, and from this cause it was long before philosophers could convince the popular mind that the earth actually was in motion.

In a carriage moving along a smooth road, and the blinds down, a person is unaware of his actual progress.

In a cabin of a ship, when sailing at a quick rate, the motion of progress or direction is unknown; the waves are heard flapping against the ship's side, but whether the vessel be moving slowly, quickly, or at all, cannot be stated by the

passenger. When sailing with the shore in view, the light-houses, churches, and trees behind, seem receding, and those in advance coming forward, as if to welcome our visit. When a ship at sea sails as quickly as another, to the persons on board the ships seem to make no progress; if one ship passes another, the people in the ship left behind think they are at rest, and the other vessel only in motion; while to those on board the swifter vessel the other appears to be receding. This all shows how insensible we are to the motion in which we participate, and how the senses may be deceived thereby.

When passing through a tunnel on a railway, or shut up in a carriage, we are unconscious of a change of place. On moving swiftly in a railway carriage, and looking steadily at an object, the landscape seems as if it was reeling round in an eddy, and the horseman on the road looks as if he and his galloping steed strove in vain to progress, and to be whirling swiftly backwards. Thus sight is deceived, and *seeing* is *not* believing.

Relative Motion is that of a body that is in motion with regard to one thing and at rest with regard to another. Thus, if a man be on a barge sailing down the river, and walk from the stem to the stern at the same rate as the tide is carrying the barge, he will be in motion relatively to the barge, but at rest as respects the bottom of the river or its banks.

Absolute Motion applies to the heavenly bodies, including our own earth: it is the movement from one part of space to another. By judging the sun to be a fixed body, the motion of the earth is taken relatively to it; but the sun, says Sir John Herschel, has an independent motion of its own of 422,000 miles per day, carrying with it the planets and comets.

Peters states that the sun, attended by all its planets, satellites, and comets, is sweeping through space with a velocity which causes it to pass over a distance equal to 33,350,000 miles in every year.

Maedler, after a profound examination, has arrived at the conclusion that the central sun in our astral system is Alcyone, the principal star in the group of the Pleiades, and that this is the centre of gravity, around which the sun and stars composing our system are all revolving. The distance of our sun from Alcyone is said to be so great, that light requires 537 years to pass from the one to the other, and that it would take

18,000,000 years for our sun, with all its planets, satellites, and comets, to complete one revolution around its grand centre.

Rapid Motion is such as light, electricity, or lightning.

Light travels about 192,000 miles in a second, and therefore would pass around the globe eight times during that small portion of man's mode of measuring periods. Yet light from a nebula, that may be seen by the naked eye, though travelling at a rate of 12,000,000 of miles in a minute, takes 60,000 years to accomplish its journey to our globe.

Electricity, as in the telegraph, speeds at the rate of 285,000 miles in a second; hence would perform its journey nearly twelve times around the earth in that fraction of time.

Slow Motion is such as the growth of plants and animals, the motion of the hour-pointer on the clock, or the shadow on a sun-dial.

Rectilinear Motion means that which is in a *straight line*. Thus, a body that moves in a direct line to a certain place is said to have a rectilinear motion. A stone dropped to the ground is an instance.

Curvilinear is a bent, arched *Motion*; as when water is pumped from a fire-engine; a stone cast slantingly, for then it does not go straight, but is continually changing its direction.

Uniform Motion is when a body passes over a certain space in a certain time, and continues to do so with regularity. The seconds, minute, and hour-pointers of the clock do so in the particular parts of the circles to which they are adapted.

Accelerated Motion is when a body increases in rapidity as it progresses. A stone down a mountain increases in speed as it advances towards the bottom; a railway-train down an inclined plane will start slowly, but rush with impetuous velocity as it gains the bottom of the incline.

Retarded Motion is when a moving body becomes slower and slower in action as it advances. A ball cast along a pavement illustrates this; or a stone thrown upwards into the air, which moves less and less quickly until it stops, and then commences its descent.

Inertia or Inactivity of Matter.

All matter is said to resist a change of state, from rest to motion, or from motion to rest; and this resistance of a body at rest to being put in motion, or of a body in motion to be stopped and rest, is called the inertia of matter. It signifies simply

the *persistence* of matter to remain as it is, and the necessity of *force* to produce a change of any kind, either as to its motion or direction. Matter at rest resists any force applied to move it. Matter in motion tends to move for ever, and resists any force applied to stop it.

In a railway-carriage, on the commencement of motion, a jerk or tug is given, when every one is thrown backward; this arises from the body being at rest, and resisting the commencement of motion, which is communicated suddenly; and if the train be quickly stopped, the body, which then has gained the motion of the carriage, is still advancing, and is thrown forward.

When standing in a boat which is heaved off from the shore, the feet are dragged away with the boat, but the body being at rest, falls towards the shore, resisting the motion; when the boat suddenly stops, the passengers are thrown forward, from the same reason as given in the case of the carriage.

Dr. Arnott relates that a young man unpractised in driving, having run his curricle against a heavy carriage on the road, foolishly and dishonestly excused his awkwardness in a way which led to his father's prosecuting the coachman for furious driving. The youth and his servant both gave evidence that the shock of the carriage threw them over their horses' heads, and thus they lost their cause, by unwittingly proving that the faulty velocity was their own.

A conductor jumping from an omnibus in motion, as soon as he touches the ground, runs forward a few steps, because his body having the forward motion of the vehicle, it must be continued until he gets clear of it, otherwise he would fall.

A person may jump from a moderately high cart or carriage at rest without injury; but when they are in motion, if he attempt to jump in the opposite direction, he is dashed on the ground. Thus, a person may step out of a railway-carriage at rest without injury, but when in rapid motion it would be almost sure death; the velocity of the carriage being conveyed to the body, it meets the earth with all that force.

A person sitting carelessly on a horse, and the animal receiving a blow, from which it starts suddenly forward, the rider finds himself on *terra firma*. Matter in a state of rest, as the equestrian's body, resists an attempt to move it.

At an amphitheatre, when standing on the back of a galloping horse, the performer will leap over a garter, or through a

hoop. In doing so he only leaps up; for having already the motion of the horse, he goes forward at the same rate as when on its back: were he to add force to this progressive motion, he would leap over the horse's head. Matter in motion tends to persist in that motion. A ball thrown from the hand would move onwards in the same direction *for ever*, were it not that the force of gravitation draws it downward.

Fig. 27.

If a card be balanced on the tip of a finger, then a coin placed on the card, and the latter receive a smart tap, it will fly away, leaving the coin on the finger-end (fig. 27).

Fig. 28.

Motion caused by Force.

To put a body in motion requires force, and according to the

quantity of matter, so is *the quantity of force* required to give different bulks the *same velocity*.

If a quoit of one pound be pitched ten yards, it will require double the force to pitch one weighing two pounds the same distance.

If a ball be thrown carelessly at a mark, its motion is comparatively slow to what it would be if the hand were drawn back, and the ball driven with the utmost force of the person; for according to the force is the motion produced.

To move, then, a heavy body as quickly as a lighter one requires increase of force. If a musket-ball and a cannon-ball have to move over the same space of ground at the same time, the atoms of matter in the cannon-ball will require pounds of gunpowder to the ounce required to move the comparatively few atoms of the musket-ball.

The same force applied to different quantities of matter moves them in proportion to their weight. A man in a racing skiff passes over a great space with rapidity. The same man, exerting the same amount of strength, and towing a barge, moves more slowly; and when tugging at a ship with all his might, his progress is infinitesimal.

Laws of Motion.

Law 1.—The first law of motion was laid down by Kepler, the great predecessor of Newton: it is, "That a body will continue in a state of rest, or of uniform motion in a straight line, until it is compelled to change its state from some form impressed upon it." This means, that a body will continue at rest if force be not used to move it; and that, when moved, every thing would move straight forward and uniformly, if some power was not applied to bend its motion, or stop it entirely. It is in fact the law of inertia, and has already been explained under that head.

A body once set in motion would never stop, did not friction, gravity, or resistance of the air oppose it, and restore it to rest. A stone flung into the air would move on for ever, if the air did not resist its progress, and gravity bring it down to the earth. A marble rolled amongst grass, on a gravel path, a smooth pavement, or on ice, has a proportionate progress; moving an immense distance on smooth ice to what it would on grass, because it has less friction to overcome on the ice than the grass.

Were there no such things as friction, gravity, or resistance of atmosphere, there would be no reason why a thing once put in motion should not so continue for ever, and thus have perpetual motion.

Law 2.—The second law of motion is due to Newton: it is, "That every change of motion is in proportion to the force that makes the change, and in the direction of that straight line in which the force is impressed."

A football may receive a kick, sending it in a direct line; but another person gives it a blow which turns it out of its path, and changes its direction. When a force acts on a body in motion, it produces the same effect as if it acted on a body at rest. This new force, if along with that previously existing, produces an intermixed result, by what is called *composition of motion.*

According to the charge put into a gun, so will be the distance to which a bullet will be driven. But when the bullet is discharged, gravity acts upon and pulls it to the earth, and thus its direction is changed from a straight to a curved line.

Law 3.—To Galileo we owe this law, which is, "That action and reaction are always equal and in opposite directions."

Thus, if an anvil be struck by a hammer, it resists with a force equal to the blow. When a tennis-ball is struck against a wall, the wall resists with equal force, and drives it back again, in an opposite direction.

A horse dragging a load is drawn back with force equal to the weight of the load. That is, if a horse's strength be equal to one ton, and a weight of one ton be placed for him to draw, this weight will hold him back; but if his strength be two tons, he loses one ton of it by the weight, and with his other ton of strength drags it onward; again, if he progress two miles an hour with the one ton, exerting himself as much without the weight, he would advance four miles an hour.

If a man in a boat pull another boat towards him, and the boats be of equal weight, they will meet exactly half-way.

It is by the resistance of the water against the oar that the boat is moved on its journey.

A bird flying strikes the air with its wings; if with force equal to its weight, it keeps itself in its position; if with less force it sinks, and if with greater force it rises.

If we step on a quicksand we sink, because there is no equal resistance to our pressure; but on the earth the resistance is equal to our pressure, and therefore we feel safe and steady.

Composition of Forces.

When one force acts upon a body, it moves in the direction of that force; but when two forces act at the same time, as it cannot move two ways at once, it takes a middle course, and this path is called the *resultant* or *equivalent*; that is, it is the result of a *composition of forces*.

If a vessel has a strong east wind that would blow it to the west, with a current from the south which would carry it to the north, and these two forces, the wind and current, act equally, the vessel neither goes to the north nor to the west, but takes a middle course between them, which is called the diagonal; and in this case the diagonal will be that of a square, the equal sides of which represent the two equal forces (fig. 29).

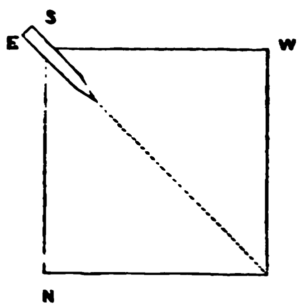


Fig. 29.

When the two forces acting on a body are not equal, then its motion is different, according to their degrees of strength.

Here the current is not so powerful as the wind, and the vessel is impelled so much further in the direction of the wind than in the direction of the current. The long side of the parallelogram represents the current, the short side the less powerful wind. The resultant motion is shown by the diagonal of the figure. This is the *parallelogram of forces* (fig. 30).

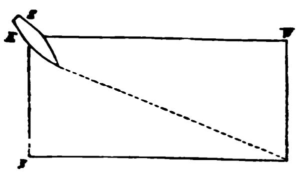


Fig. 30.

(A parallelogram is a plane figure whose opposite sides are parallel and equal to one another.)

Scientific men call such forces *components*; that is, the two go to make one, and this one is the *resultant*; they can calcu-

late them to a nicety; and, as of all laws of nature, make them a mathematical certainty. They find that a *resultant* force is as the square root of the united squares of the two component forces. Suppose the force of the wind would take the vessel eight miles an hour, and the current six miles an hour,—square these powers; 8 times 8 are 64, and 6 times 6 are 36; then add the numbers together—64 and 36 are equal to 100,—take the square root of 100, which is 10, so that the vessel has gone by the two forces 10 miles in the hour, which is more than it would have done by either of the forces separately, for with one it would only have gone six miles, with the other only eight miles. This rule is true only when the two forces are at right angles to one another.

When two forces are almost in opposite directions, which may be illustrated by opening a pair of compasses almost straight, then the resultant line is very short, which proves that two such forces tend to destroy each other.

Should three or more forces in different directions act on a body, then the resultant line can be found thus:—

Here are three forces, A B, A C and A D (fig. 31); the resultant of A B, A C is first found in the manner before stated, which will be the dotted line A F; then the forces A D and A F will give the line A E, which is the resultant of the three forces.

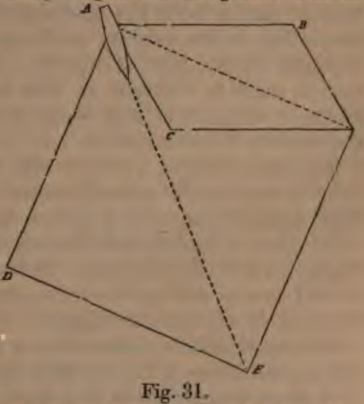


Fig. 31.

Velocity.

Intensity, not quantity, of motion is meant by velocity. Velocity, or swiftness, is measured by the time employed in moving over a certain space. Thus, if a cannon-ball move about 1000 feet in a second, and a railway-engine about 100 feet in the same time, the ball has ten times the velocity of the engine.

It has been shown that every atom of matter is equally attracted or pulled to the earth ; yet, if a shilling and a feather be dropped, the difference in their velocity or swiftness in reaching the ground is considerable : but this arises from the atoms of which the feather is composed being more expanded, and the resistance of the air causing it to fall slowly; take away the air, as can be done by an air-pump, and the feather and coin will fall with almost equal rapidity. If a sovereign was beaten out into a thin leaf, the resistance of the air would prevent it reaching the ground with the same velocity as when in the form of a coin. Thus, velocity is retarded or diminished by the resistance of the atmosphere.

Momentum.

The term momentum is used to signify the quantity of motion that a body has accumulated within itself, and is in proportion to its velocity and mass of matter. Momentum depends on the law of inertia. A body that has acquired motion tends to continue in that motion, and resists any obstacle or attempt to stop it, in proportion to its weight, and the velocity it has acquired.

The motion given by force can be communicated from one body to another, in quantity equal to that which it possesses. Thus a person may roll a cannon-ball from his hand against a thick piece of timber, and the momentum not being much, the timber receives little injury. If the ball be fired at a distance, it will bruise and splinter the wood; but if fired at a short distance, it will pass through it.

We communicate momentum to a hammer in driving a nail, but a greater one when we fix a stake.

A great velocity given to a small body may equal in effect a less velocity given to a large one. Thus a battering-ram does no more than a cannon-ball. A cannon-ball 28 lb. weight, passing at a rate of 1072 feet per second, would equal a battering-ram of 15,000 lb. weight moved at two feet per second. This is calculated by multiplying the weight by the space passed over by the ram, equal to 30,000 ; this again is divided by the weight of the ball, 28, and the velocity necessary for the ball is thus known,—nearly 1072 feet per second.

A *light* body with increased momentum will strike as powerfully as a *heavier one* having less momentum or velocity : thus

a ball 3 lb. weight with a momentum of 300 feet per second, will strike with as much force as a 30 lb. ball driven at a rate of 30 feet per second.

As velocity is attained by the act of falling, we find it necessary to lay down heavy weights gently. If a box of 100 lb. weight was placed easily down on a floor, no injury would accrue; but if dropped at a height of an inch and a quarter, the momentum would make it fall with a weight of 200 lb.; if at five inches, with a force of 400 lb.

To such an increasing force as this the term *momentum* is also applied, though somewhat irregularly. In this sense it signifies *a velocity continually increasing by a force continually acting*. This is also called an acceleration of motion.

If a boy throw a cricket-ball up in the air 10 feet high, and catch it in his hands, he does not feel any particular hurt; if he cast it upwards 20 feet, he receives a good smart blow on its return; and if 30 feet high, he has to ease the blow of the ball by giving way to it, or otherwise his hands might be bruised.

A ball dropped from the hand at the height of the head, is easily caught by the time it reaches the breast; but the lower it gets, the more difficult it is to catch. A person may spring from a chair and feel no harm; in leaping from a high window he may receive a sprain or a broken bone; but in jumping from a house-top he would probably be killed.

Falling bodies, every moment they are descending, collect more velocity and momentum.

If a person be on the top of a hill or mountain, and move a large stone over its side, it goes the first few feet hesitatingly, as if with reluctance; but gradually, as it proceeds, its motion is increased to great rapidity, until it has rolled beyond the foot of the mountain, along the plains below.

A horse in kicking draws its leg up, and, as the space it has to pass through adds to the velocity, is enabled to inflict frightful injury. Boxers keep their arms far back, that they may give a powerful blow when striking at arm's length. Anchor-smiths, in wielding a blow, swing the hammer round, that it may have accelerated power in forming the ponderous instrument that has to grapple with tides and storms. In pile-driving, a weight is pulled up to a great height, and let fall, to force the beam into the bed of the river.

The distance a bullet may be sent depends much on the length of the barrel, or the space in which force may be accumulated. The clever deer-hunters and pigeon-shooters in America use enormously long-barrelled rifles.

The velocity gained by going down a steep incline will cause a body to rise up an opposite acclivity. If a horse with a cart be driven fast down hill, the momentum acquired will assist him in mounting the ascent beyond.

A monkey drops a cocoa-nut from a height, that its shell may be broken. Some birds drop shell-fish on rocks, that they may feast on the food inside.

Velocity of Falling Bodies.

It has been just stated that when a body is let fall from a height, as the attraction of gravitation is continually acting, so the velocity increases every instant. By accurate calculations, it is found that the increase is exactly as the odd numbers 1, 3, 5, 7, 9, &c.; that is, in one second of time a body falls through 16 feet of space; in the next second, it passes through three times 16 feet, that is, 48 feet; in the third second, its progress is five times 16 feet, or 80 feet; in the fourth second, seven times 16 feet, or 112 feet: thus the whole of the space passed through in four seconds will be 16, 48, 80, and 112 feet, which, added together, is 256 feet.

The rule deduced from this is, "The spaces described by a body falling freely from a state of rest increase as the ***squares*** of the times increase." The seconds, that is "the times," multiplied by themselves, give "the squares," and this result multiplied by sixteen, that is, the space described by the first second, the answer will be the number of feet through which the body has fallen in a certain number of seconds. The square of 2 being 4, in two seconds the body will have fallen 64 feet; for a similar reason, in four seconds 256 feet will be traversed. On dividing the distance by 16, and taking the square root of the result, the *time* employed is represented. Heights can be roughly measured by this rule.

Were a weight dropped from a pillar, and the time of its falling to be three seconds, then multiply three by three, which is nine, and multiply again by sixteen, the result will be 144 feet—the height of the pillar.

A stone dropped down a well or mine, and the time of its

falling being found by a watch to be four seconds, four times four is equal to sixteen, which, multiplied by sixteen, the depth of the well or mine will be 256 feet.

The real distance a body falls in a second is 16 feet 1 inch; but the use of a whole number is less confusing to the comprehension than when fractional parts are introduced.

Everything would fall with the same velocity, were it not that the resistance of the atmosphere acts more on one body than upon another. If this were not the case, a feather would fall as rapidly as a bullet.

Reflexion of Motion.

A ball or a marble being driven in a perpendicular line

Fig. 32.

against a wall, the reaction of the wall will cause it to rebound in the same line as it proceeded towards the wall.

If a ball be bowled obliquely, on hitting a point it will rebound in a similarly oblique line, in an opposite direction.

The ball thus thrown by the boy at *a* (fig. 32) hits the wall at *c*, and then progresses towards the boy at *d*, forming as equal an angle on one side as on the other, which may be known by drawing a straight line from the point of the wall where the ball hit. The angle formed by the line indicating the direction of the ball and by the perpendicular dotted line from the point of contact is called the *angle of incidence*; and the *angle of reflexion* is the angle contained between the same perpendicular dotted line, and the line drawn representing the path of the ball after it has rebounded from the wall. It is a general law, that these two angles are equal to each other. It will afterwards be seen that this rule applies as much to a ray of light as to a line of force.

Reaction.

The law of reaction has been laid down in law 3; but the following examples will assist in elucidating the subject:—

On board our men-of-war, there are contrivances for the recoil of the cannon that are fired, for the cannon receives as much momentum as the ball; but the momentum being distributed through the large mass of the cannon, it is more easily arrested than the smaller mass of the cannon-ball.

Most persons have felt the blow of a gun on firing it when not placed tightly against the shoulder. By having it placed to the shoulder, there is the greater mass to receive the momentum caused by the recoil.

A vessel chasing a smuggler retards her motion in firing her bow guns, while the smuggler quickens hers by firing her stern cannon.

An elastic body yields to pressure, but strives to resumé its formèr shape. Thus, a piece of cane when bent endeavours to gain its former straightness.

If a row of billiard-balls be placed in contact, and another ball be driven against the first one, the driven ball stops, but it communicates its motion to the next, which again transfers it to its neighbour, and so on, until the last ball having no other to communicate it to, flies off with the motion of the ball that took up its place before the first one.

The second ball has stopped the first by its inertia, but the immediate *reaction* causes the motion it has arrested to be

communicated to itself. Instances of this kind might be multiplied almost indefinitely.

On the continual alternation of action and reaction, depends the familiar phenomenon of the *vibration* of elastic solids, as of a piece of wood, steel, or bell-metal.

Centrifugal Force.

It has been seen that the tendency of all matter in motion is to move in a straight line, and that when it does not do so, some power acts upon it and prevents it. The earth has a motion nearly in a circle around the sun; its tendency is to fly off in a straight line, but it is prevented from doing so by the attraction of the sun, which is in opposition to the inertia, or persistence of matter in motion. This tendency to move away in a straight line, is called the *centrifugal* or centre-flying force.

A plummet fastened to a string, and whirled round, makes a constant effort to move in a straight line; but from being held to a centre every movement is bent: cut the string, and it will dart off in a direct line, which is a tangent to its circular motion. This plummet may be taken to represent the earth, and the string which prevents it from flying off, the attraction of the sun. The motion of a wheel round a fixed centre or axis is explained in the same manner (fig. 33).

Fig. 33.

Supposing a rotatory or vibratory motion to be given to a body of circular or other shape, and this body have some moveable particles loosely attached to it, these will tend to fly off from it in a straight line; that is to say, they act in obedience to the first force. All force tends to cause motion in a straight line. But a second force, which holds the firm body to a centre, changes its movement to rotation. The moveable particles not being held, they fly off, as the water from a twirling mop, and are said to do so by *centrifugal force*.

When a dog comes out of water, it shakes itself, and the

water flies off in direct lines. The mud on a carriage-wheel flies away in a straight line from different parts.

The potter makes use of centrifugal force to aid in his useful handicraft. A piece of clay is placed on a rapidly-moving flat wheel, and the clay flattens out in endeavouring to move from the centre; with the aid of his fingers and a little tool, he turns and moulds it as he pleases.

Our common window-glass is also by this force manufactured into sheets. An iron rod, holding a mass of molten glass, is made to turn rapidly round; the glass is spread out on a table into a thin round plate, from which, when cool and hard, are cut different-sized panes.

Centripetal Force.

This means centre-seeking force. It is the power that draws inward, towards the centre of a circle.

It is the opponent of the *centrifugal force* which has just been illustrated. It is the string that holds the plummet, the sun that keeps the world in rotation.

Though distinctive names are given to these two powers, it is not to be supposed that they differ in any manner from other kinds of force. The only use of the terms is in the explanation of the phenomenon of rotation round a centre, familiar to us on the earth, and exemplified on a grand scale in the heavens. Further, it is simply when taken together, or opposed to one another, that the words have any real significance. Centrifugal force, *alone*, is motion in a right line. Centripetal force, *alone*, is attraction.

The great centripetal force in nature is the attraction of gravitation. This has already been explained to be the force by which all greater bodies attract lesser ones, by which our earth draws to itself all matter on its surface, and the sun draws to itself our earth.

The sun is the centripetal power which balances the centrifugal motion of the earth, and thus keeps it in its orbit. Were the centripetal force to predominate, the earth and sun would continually approach each other till they became one mass; on the contrary, had the centrifugal force predominated, our sun by this time would have been of but little use to us from its great distance.

If a stone be placed in a sling, and whirled round while the

cord is held, that is the centripetal force; but when one of the cords is let loose, the stone darts off in a straight direction, and that is centrifugal force.

It was formerly a favourite performance among jugglers, to place a glass of water in a hoop and swing it round, then restore it to rest without spilling a drop.

A horseman on turning a sharp corner leans inwards, that he may overcome the centrifugal force, *i. e.* the tendency to move straight on.

At exhibitions of horsemanship, while riding round the circus, both man and horse lean toward the centre, and the faster they go the more they incline inward, that their centripetal position may equalise their centrifugal force.

In skating, a person describing a circle leans inwards in such a manner that unless moving he would fall; the motion prevents his downward progress, and he wheels about in graceful action.

Two common phenomena, not in reality so simple as they seem, may demand some explanation here—the *rolling of a ball*, and the *rotation of a top*. Suppose a ball, to which momentum has been given, comes in contact with the ground; the part which touches the ground is hindered from moving on by friction. The upper part moves on, but being hindered by the state of rest to which the lower part has come, and kept to it by attraction, it cannot move in a straight line, but its momentum carries it onwards until it too touches the ground at some distance off. The part at first lowest has moved round, and is now uppermost, and free to move onwards in its turn. These opposite movements combine to cause the motion of *rolling*.

A circular body, as a top, spinning, or rotating round its axis, is a similar instance to that of the rotation of the earth, inasmuch as it results from a compromise between the centrifugal and centripetal forces. The latter consists here in the mutual attraction of the particles. Let us consider the case. In setting a top going we communicate two opposite motions to it, as is easily discovered when we *twirl* it with the finger and thumb. To one side of the circle we communicate a motion in one direction, to the other side in the contrary direction. The tendency of both is to continue in a right line; were the top made of loose material, this would really

happen, and its parts would fly asunder, just as we see a heap of sand, which has been caused to rotate by a wind-eddy, fly abroad in a radiating manner when the gust has ceased. But the particles of the top are held together to a common centre. Each side moves on in the direction of the motion given to it, but being held to this centre, it moves in a circle, as the plummet held by a string. The opposite side, having acquired the same motion, causes an exact balance of force, and the whole moves round its axis; rotation is produced, which may be called *a compromise between two opposite forces acting on the same body*. Each force may be said to have its own way on one side of the top. As all motion tends to continue for ever, this rotation would go on without limit, were it not for the friction of the sides with the atmosphere, and of the point of the top with the ground. If the two rotating forces be sufficiently strong, they may overcome the force of gravity, and the top will continue to spin on its peg, whether or not it be exactly balanced on its centre.

Motion of Projectiles.

When a ball is fired from a cannon, it is affected by two forces; first, the power that drives it forward, and secondly, the attraction to the earth. The force impelling it forward may be increased, but the power of gravity is never decreased. Thus, whether a ball be driven in a straight line one mile or two miles, it reaches the ground as soon at two miles' distance as at one mile.

A ball dropped from the mouth of a cannon would reach the ground at the same time, from gravity, as a ball fired the distance of a mile touches the earth, provided it were fired in a line parallel with the earth's surface.

When anything is forcibly thrown forward, as a bullet, a stone, or an arrow, and the direction given is that of a straight line, it will be seen to have taken a bent or curvilinear direction. If water be forced from the spout of a pump, according to the force given does the water take a short or wide bending motion. The curve described by any body thus projected, is termed by mathematicians a parabola.

On firing a cannon, this bent motion, from gravity, keeps gradually accumulating, so that the ball is continually approaching the earth, and as more force is applied, the sweep

of the curve is enlarged. If the force was great enough to carry the ball twenty miles, the curve would elongate, and if fifty miles it would be still larger, and so it would go on until, with increased force, it passed around the earth, and formed a perfect circle.

Were it possible to give a greater force than would send a ball around the earth, it would fly off, and become an independent body, rolling in space.

The motions of the earth and planets have been already stated to arise from the centrifugal force with which they are projected into space being counteracted by the centripetal, by which they have gained that curved motion which they invariably pursue; but from the forces not being at right angles, their path is not a perfect circle.

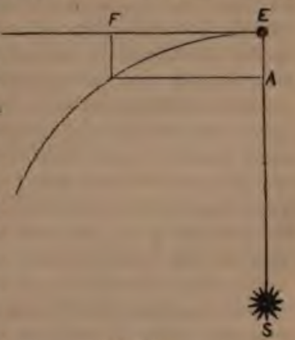


Fig. 34.

Suppose S (fig. 34) to be the sun and E the earth, that the earth is projected with a force sufficient to send it in a month to F, while the sun's attraction would bring it in that space of time to A, then the two forces acting together on the earth, cause it either to fly off in a straight line or to fall into the sun; but being controlled by each, continually striving to get away while held fast by attraction, it proceeds in a circular path. The attraction to the sun is called the centripetal force, and the force with which, if alone, it would go in a straight line, the centrifugal.

The Pendulum.

A weight, fastened to a piece of string attached to a beam, and pulled to one side, then let fall, will rise up on the opposite side and describe a curve. This is from having, when descending, received as much accelerated motion as carries it up the opposite side to an equal height. Again descending, by virtue of the force of gravity, it rises up the opposite side for the same reason as before. The momentum will cause it to keep in this motion, until the resistance of the air gradually lessens he length of the curve, and it becomes stationary. This

motion of swinging backwards and forwards is called vibration or oscillation.

The pendulum is commonly a thin rod of metal wire, hung from a point A (fig. 35), by a thin metal spring or other contrivance, to allow the pendulum to swing in the proper curve, with a weight at its lower extremity, called the bob B. When the ball is raised to C, it falls, by the force of gravity, like a ball rolling down a slope to the place at which it was at rest, B; and as all bodies have their motions as much accelerated whilst descending, as retarded when ascending, it arrives by this reaction at D. Next, gravity pulls it back again to B, with accelerated motion sufficient to send it again to C; and thus it would go on for ever, were there neither air nor friction to act as an impediment, and bring it to a rest. From C to D is called its path or arc. The *duration* of an oscillation is the time required for passing along its path or arc.

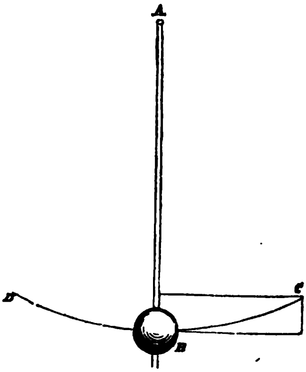


Fig. 35.—Pendulum.

Viewing the motion of the pendulum in the parallelogram of the diagram, it will be seen to act from two forces, the one direction being that of gravity downwards, and the other rectilinear, in the direction B, while the resultant of the two forces is a curve, which, if the point of attachment above remains fixed, will be the segment of a circle.

Whether a pendulum be long or short, its beats are equal *if the curve be a cycloid*, which differs a little from a circle; and it is this property that constitutes its immense value to man.

The motion of a pendulum is calculated just as precisely as any other simple question of arithmetic. Thus if the motion of one pendulum takes one second, and another two seconds, the length of the pendulum will be as 1 to 4; that is, the times are multiplied by themselves, as three seconds, the length 9; four seconds, the length 16. Thus, then, the duration of an oscillation being as whole numbers, the length of the pendulum will be as the squares.

In London a pendulum *will beat seconds* if its length be a trifle more than 39 inches; for half seconds its length would be nearly 10 inches, thus only about a fourth; a quarter second pendulum nearly 2½ inches, four times less again. Then, for a pendulum to beat two seconds would require one four times as long as a seconds' pendulum. This law will be seen to be the same as that of the speed of a falling body increasing four times in two seconds.

A clock is composed of a few wheels which are dragged round by weights attached, or by a spring in a box: the movement of these wheels would be irregular were they not governed by the regular motions of the pendulum; without the pendulum, the hours would not be pointed out, and the clock then of little use. The weight or spring causes the movement, but its rate depends solely on the pendulum. The pendulum is hooked on to a part of the clock, and each time as it vibrates it allows a cog of a wheel to pass; this wheel has sixty of those cogs around it; then, if the pendulum swings sixty times in one minute, it just occupies that space of time in passing round; to this wheel a pointer is fixed, which shows on the face of the clock sixty movements of seconds, completing the circle in one minute. The sixty-cogged wheel moves on another wheel at a slower rate, which shows the hours on the dial. Other wheels for other purposes are sometimes added, which are all under the regulation of the pendulum.

The length of the seconds' pendulum varies in different places; it must be a little longer at Edinburgh than in London; for it is influenced by that universal principle, gravity, as all other bodies are. The thousandth part of an inch in length varies or adjusts its movements, to the extent of a second in a day.

At the Equator and at the Poles, the different thickness of the earth is such as to necessitate a difference of one-fifth of an inch in the length of the pendulum.

The length of a pendulum must be measured from *the point of suspension* to *the centre of the oscillation.*

The invention of the long pendulum is claimed by a London artist, named Richard Harris, who applied it to a clock in 1611, which is seventeen years before the time that Galileo states he directed one to be made.

We have seen, in a former part of this work, that the heat and cold of the seasons affect iron, and therefore must have an

influence on the metal of the rod of the pendulum. To avoid this consequence, serious in many affairs of life, what is called a gridiron pendulum has been invented, which consists of several rods of different metals, so adjusted as to counterbalance the various effects of the seasons.

Compensation is effected in the great clock of the Royal Exchange, by the equivalent contraction and expansion of a system of combined rods of zinc and steel: the centre rod is of steel, the whole length of the pendulum; and at the bottom of the pendulum, as shown in the figure, is placed the zinc column. It is evident, that as the rod lengthens downwards by an increase of heat, the column of zinc *standing on the nut*, perfectly free of the steel rod, will expand upwards. On the top of the column of zinc is fixed a metal cap, into which are firmly fixed two steel rods, and at the bottom of them is the pendulum-bob, from which it follows that the bob hangs by means of these two rods from the top of the zinc column, and quite independent of the centre rod. The zinc column, expanding upwards by an increase of temperature, raises the pendulum-bob, while at the same time the rod lengthens by the increase of heat. The zinc column is made shorter than the steel rod, because zinc expands and contracts more than steel, for equal increase and decrease of heat.

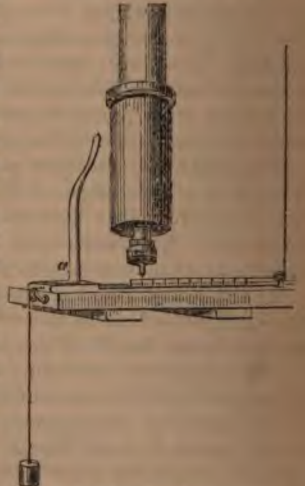


Fig. 36.—Pendulum.

When this clock was required to be set to within a fraction of a second, it was found that if the pendulum were stopped by hand, it would be next to impossible to put so large and heavy a mass—nearly four cwt.—in motion to such a small portion of time. Again, the difficulty of setting it to vibrate in the same plane, as well as to give the usual extent of arc of vibration, rendered it impossible to accomplish the regulation to the required nicety. Mr. Airy

at once suggested an ingenious and simple mode of overcoming the difficulty. He directed that the clock should be started at

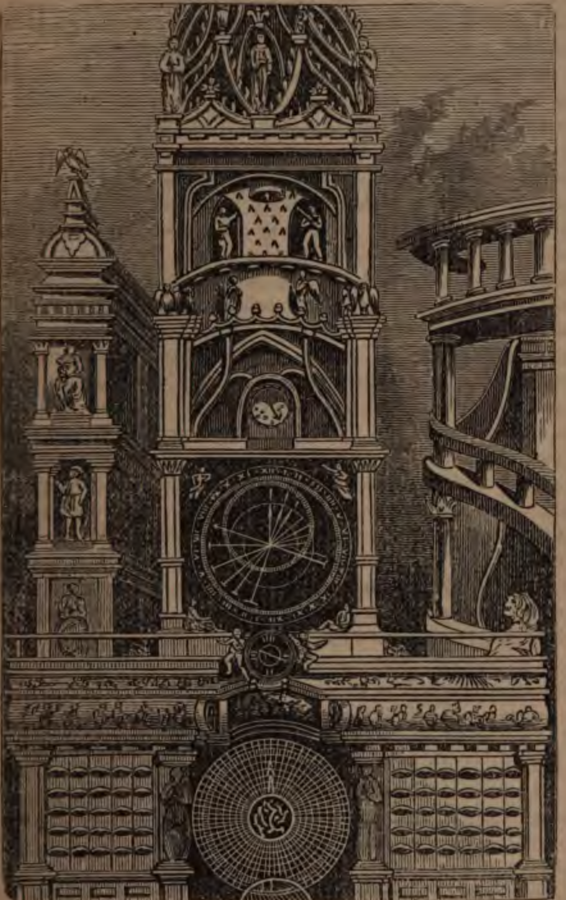


Fig. 37.—The Strasburg Clock.

a very small losing rate, and then that a spring shown at *a* (fig. 36), should be brought against the pendulum, by drawing a line

passing into the clock room, so that it might be made to touch the pendulum slightly, and cause a corresponding gain in the clock. This it does to the minutest fraction of a second. In fact, it affords the means of putting the beats of a great turret clock and a comparing chronometer in coincidence.

The regulation of the pendulum in most clocks is effected by a screw at the bottom, which increases or diminishes the distance of the bob from the point of suspension.

The most remarkable piece of mechanism worked by the movements of a clock is that at Strasburg. The dial-plate exhibits a celestial globe, with the motions of the sun, moon, earth, and planets, the phases of the moon, and a perpetual almanac on which the day of the month is pointed out by a statue. The first quarter of the hour is struck by a child with an apple, the second by a boy with an arrow, the third by a man in his prime with a staff, and the last quarter by an old man with a crutch. The hour is heralded by an angel, who opens a door, and salutes the Virgin Mary; another angel turns an hour-glass on the completion of the hour. A golden cock at the same time flaps its wings, and stretches its neck to crow (fig. 37).

In that useful companion to man, a watch, the weights of a Dutch clock are substituted by a spring. This spring, acting in all positions, enables the little instrument to perform its duties regularly, in whatever way it may be hung, laid, or carried. The fusee on which the chain is wound is a varied lever, so that, as the action of the main-spring is lessened by unwinding, it acts in such increasing proportion that a constant quantity of power is in existence. The *balance-wheel* is the representative of the pendulum; instead of the oscillation produced by gravity on the pendulum, the watch has a delicate spiral spring to which the balance-wheel is attached; the elasticity of this spring is such that it bends and unbends with uniformity, and equalises the motion of the balance-wheel.

Fig. 38.

The *chronometer*, on whose dial the mariner gazes to know

his position on the ocean (which it indicates by the difference between its time and that of the sun), is a large watch, so carefully constructed, so accurate in its movements, that it will rarely vary more than a second in a year: were its truth to deviate a few seconds, it might be the cause of death to those confiding in its guidance. The chronometer, however, differs from the common watch in the balance-wheel not being an entire circle, but more as if an S was intended, only the middle part, connecting the top and bottom segments of circles, is a straight line; at the end of each of these parts of the circle is placed a small ball. This balance is composed of different metals soldered together, to prevent the effects of heat or cold on it. There are other contrivances or improvements on common watches in the chronometers which it would be difficult to explain (fig. 38).

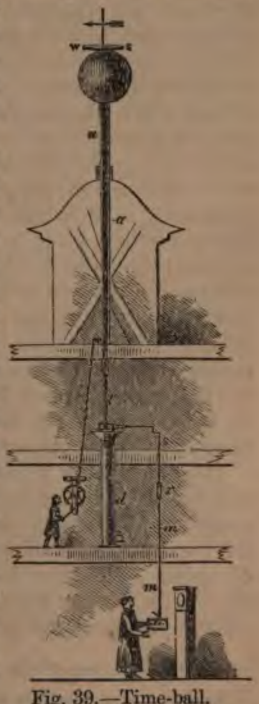


Fig. 39.—Time-ball.

The Time-ball at Greenwich is hat exact monitor by which our commercial navy on the Thames regulate their time-keepers. At five minutes to one o'clock every day the ball is hoisted half-mast high; it is afterwards drawn to the top. Exactly at one o'clock, mean time at Greenwich, it descends. Thus, by watching it two or three days, the errors of a chronometer are easily detected, and the mean time at all other places ascertained when the longitudes are known. The accompanying illustration exhibits a section of the first, second, and third floors, in which the apparatus is placed, which may be said to consist of a hoist for raising the ball, a trigger and discharging gear for its liberation, and a clock regulated by observation, for giving the required moment of time: *a a* (fig. 39) is the supporting shaft bearing the ball on its top and terminating below at *b* in a piston, which works in an air-

cylinder d, by which the too sudden descent of the ball is prevented; m, m, r, s is a combination of rods and levers connected with the discharging trigger.

In the second floor is a windlass, having a chain passing over a pulley, by which the ball is raised to the top of the pole. On the first floor is the discharging trigger, which is let go the moment it is one o'clock; as the ball is some seconds in falling, the first movement of it downward is the exact time.

Time-balls have lately been fixed on the top of the Electric Telegraph Offices in West Strand and Cornhill, London, both of which fall simultaneously with that at Greenwich. The plan adopted, both for dropping the ball and for the transmission of signals, is automatic, the galvanic circuit being completed by certain pins or studs affixed to the train of wheels of Mr. Shepherd's electro-magnetic clock at Greenwich. Some of these wheels carry one or more pins, according to the signals required. At one o'clock the circuit is completed, and an electro-magnet, placed near the discharging-rod of the ball apparatus, at this instant becomes a powerful magnet, and draws towards itself a piece of iron, which, till this time, supports the lever or trigger of the discharging-rod, and thus relieves the supporting-shaft with the ball at its top. In the new method the spring at the trigger is replaced by a piece of iron, and the observer, seen in the first floor of the cut, is replaced by an electro-magnet, which unerringly discharges the trigger, and causes the hour of one o'clock to be announced by the descent of the balls. In a similar manner this clock transmits signals twice a day to several railway stations.

The universality of the railway system throughout the length and breadth of the land, has rendered it a necessity to be guided in all parts of the kingdom by the same time, otherwise serious accidents might continually occur from collision of trains. Therefore Greenwich time, as announced by the time-balls, is that which now regulates the clocks of all the railways in Great Britain.

The Rotation of the Earth, as proved by the Pendulum.

Suppose a pendulum to hang from the point of suspension, in such a manner that it is free to vibrate in any direction: a certain vibration being now given to it, it will have a natural

tendency to vibrate in exactly the same direction incessantly. This depends on the law, that a certain motion once communicated, tends to continue for ever. To word it scientifically, *the plane of vibration of the pendulum is invariable.* It may be regarded as a line in space. Suppose at night the vibration points on one side towards the pole-star, on the other towards a star in the south, it will continue to vibrate in the same direction, whatever the motion of the earth may be. As the earth rotates on its axis in the twenty-four hours, it is apparent that any line (or body) on its surface must change its relation continually to a fixed line in space—in fact, rotate round it. At the Pole this rotation would be complete in twenty-four hours, at our latitude it occupies a longer time. The experiment by which is thus rendered visible the diurnal rotation of our planet was first performed by M. Foucault of Paris, in the cellar of his mother's house. It has since been repeated by Arago and other French philosophers, and by many in England. M. Foucault, in order to demonstrate it more publicly, applied the dome of the Pantheon to the object. To its centre a fine wire was attached, from which a sphere of metal, 4 to 5 inches in

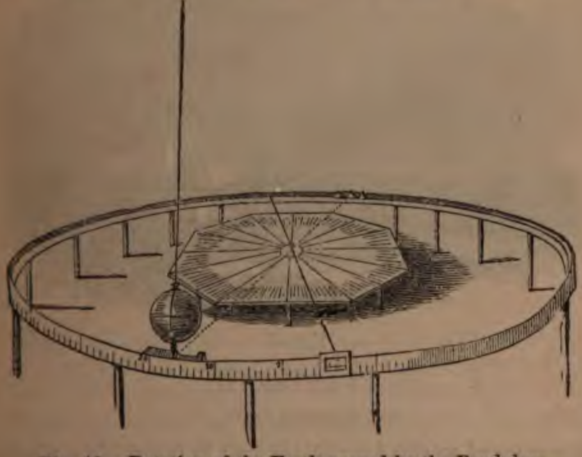


Fig. 40.—Rotation of the Earth proved by the Pendulum.

diameter, was suspended, so that it nearly touched the floor of

the building. Under it, and also in the centre, was placed a circular frame and table, as shown in fig. 40, the circumference being divided into degrees and minutes.

Care must be taken, in such an experiment, to avoid interference with the result by torsion of the wire. Some kind of ball-and-socket arrangement is needed at the point of suspension. At the Pantheon the table performed a complete revolution round the line of vibration of the pendulum in about 30 hours 40 minutes. At Dublin it is stated to have taken 28 hours 26 minutes. But the difficulty of an accurate observation is very great. However, the principle is obvious, and the demonstration complete. In an experiment on a large scale, the practised eye, aided by a proper optical instrument, may actually see the motion which the table, in common with the earth, has under the pendulum between two successive vibrations; for the ball, the second time, does not return to precisely the same point. And thus *we can see the earth move round.*

Fig. 41.

CHAPTER III.

MECHANICS.

THE science of mechanics enables man to husband his strength in the production of motion. For this purpose he resorts to the aid of appliances called *mechanical powers* or *simple machines.*

A simple machine is an instrument by which weights can be raised, the resistance of heavy bodies overcome, and motion communicated to masses of matter. It is by the application of *simple machines*, or *mechanical powers*, that man accomplishes many useful undertakings, that, without such contrivances, would be beyond his natural strength.

Complex machines may be traced to peculiar arrangements of simple mechanical powers. The natural forces or powers at the command of man for producing motion are few, being principally the strength of men and horses, running water, steam, fire, and wind.

It is the ability to regulate, accumulate, and divide the speed of such powers, and to connect, oppose, and counterbalance their different velocities, that constitutes the value of the mechanical forces to man. Machines do not beget or increase force, they only apply that which has been communicated to them in an advantageous easy manner.

The power applied must be greater than the resistance, otherwise there would be no motion.

Time is exchanged for *power*; or, as it is sometimes expressed, "what we gain in power we lose in time." This is the golden rule of mechanics. Thus if a person could raise 50 pounds to a certain height in one minute, and by the help of machinery he raises 500 lbs. to the same height, it will be found that the time occupied in lifting up the 500 lbs. would be ten minutes: thus the tenfold increased power has to have a tenfold increased time, or the work of ten minutes could have been accomplished in ten different efforts in the same time.

The primary mechanical powers are the *Lever*, the *Pulley* and the *Inclined Plane*. The *Wheel and Axle* are derived from the lever; the *Wedge* and *Screw* from the inclined plane.

The Lever.

Of all the mechanical powers the lever is the most simple. It is formed of any strong substance, in the shape of a beam or rod, which rests on a prop or axis called a fulcrum, which is its centre of motion. There are three kinds of levers. The following is an exemplification of the *first*.

In this diagram, *b* (fig. 42) is the lever, *a* the fulcrum, *c* the weight. By pressing down at the end *b*, the other end of the lever

raises the weight; the centre of motion is at *a*, the fulcrum. In other words, the power or force resting on the prop or fulcrum overcomes the weight or resistance. It is the property of the lever that the power increases in direct proportion with the length of the long limb. Thus if the lever be under the centre of gravity of the weight, and the length of the lever from the fulcrum be twice as long as the other part, a man can raise the weight one inch for every two inches he depresses the end of the lever. If the end of the lever be four times the length of the part from the fulcrum to the centre of gravity of the weight, then the power of raising the weight is increased four times; but the space that the *b* end of the lever will pass through is four times greater.

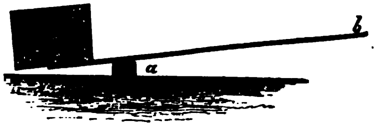


Fig. 42.

It will thus be perceived, that if a weight of one stone moves through a space of ten feet, we may raise a weight of ten stone through a space of one foot; or a weight of ten stone moving through a space of one foot will make a weight of one stone move through a space of ten feet.

If a man can raise the weight at the end of the lever, and then the lever be made twice as long, a boy of half the man's strength can raise it. Thus it is that "the force of the lever increases in proportion as the distance of the power from the fulcrum increases, and diminishes in proportion as the distance of the weight from the fulcrum increases." It was from this general law that Archimedes exclaimed, "Give me a lever long enough, and a prop strong enough, and with my own weight I will move the world." This was true; but so immense is the arc of a circle his lever would have to describe, that even if moved at the rate of 10,000 feet an hour, for about eight hours a day, it would have taken him nearly nine bilions of centuries to raise the earth an inch.

Should it be desired to know what power will balance a certain weight at the short end of the lever, it is done by multiplying the weight by the length of lever from it to the fulcrum, and then dividing the result by the other length of lever, and the result is the power required: thus if 100 lbs. be on one end of a lever 12 inches from the fulcrum,

$100 \times 12 = 1200$; then suppose the long end of the lever be 24 inches, $1200 \div 24 = 50$ lbs., the power required.

In moving barrels and very large weights, as on board ships, a *hand-spike* is the lever found best adapted to the purposes required. Carpenters, masons, and others who have to move bulky masses of matter short distances, adopt the *crowbar*, which also is a lever made of iron, having a claw at one end.

A *hammer* has usually a claw for drawing out nails; in this the power seems great, for the nail will draw an immense weight attached to it; yet because we move the hand through several inches while the nail moves only a very short way, we can draw it out in accordance with the law given above.

The *fire-poker* is a lever, having the bar of the grate for a fulcrum.

The simple lever has sometimes two arms; it is then called a double lever. *Scissors, shears, nippers, pincers, forceps, snuffers,* are of this kind, having the rivet as a fulcrum for both.

The *scale-beam* used in weighing is a simple lever. The arms (fig. 43) on each side are made of equal length, and suspended over the centre of gravity. The axis or pivot, which is the point of suspension, is sharpened to a very thin edge, sometimes equal to that of a razor, that the beam may easily turn with as little friction as possible when weights are applied in the scales. Should the arms not be of equal length, then the scales cannot act justly, unless the weights used are altered; for if one were half an inch longer than another in an arm of eight inches in length, the customer would lose an ounce in every pound of the common weights.

Fig. 43.

But sometimes, instead of the weighing-beam an instrument is used, called a *steel-yard* (fig. 44), which is a lever with arms of unequal length. The lever is suspended from a hook, which is the fulcrum or pivot, and from which the steel-yard must truly balance; this is its centre of gravity. Here one pound

weight will weigh any number of pounds that the yard is long enough to raise, and the exact weight may be measured by the distance that the small sliding weight has to be removed from the fulcrum in order to balance it.

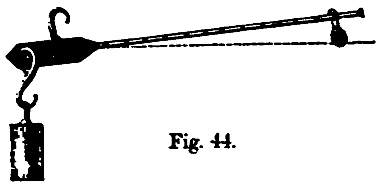


Fig. 44.

The second kind of lever is that where the fulcrum is at one end, the power at the other, and the weight in the middle.

Thus, if a mason desires to move forward a large piece of stone, instead of bearing down upon the lever to raise it up a little, he sticks his crowbar into the ground, and pushing upward, moves the stone little by little onward, the ground being the fulcrum.

Fig. 45.

A wheel-barrow affords another example: in using it, a point in the wheel of the barrow pressing on the ground is the fulcrum; the load is the weight, and the handles held by the man the power; as the person shortens or lengthens his hold on the handles, so does he move the centre of gravity to the wheel or himself.

If two men carry a load slung from a pole resting on their shoulders, and the load be in the middle between them, they have an equal share of the weight; but in proportion as it is more towards one than the other, so is the extra amount of weight to the one nearest to it. The men are the fulcra in this case; they act in that capacity the one to another, while each is also a moving power. Should the pole be eight feet long, and the weight 200 lbs., each man will bear 100 lbs. weight. Suppose that a man and a boy are set to carry this weight, and the man, from the boy's inability to carry his equal share, out of humanity places the weight four times as far from the boy,—that is, about 6 ft. 4 in. distance, and only 1 ft. 8 in. from himself,—then the boy will only have about 50 lbs. weight, while the man will have 150 lbs. to bear.

The common operation of opening a door or a box, is an

illustration of this lever; the hinges are the fulcra or centres of motion, the door or lid the resistance or weight, and the hand the moving power. The finger is painfully nipped when caught near the hinge, from that part being near the fulcrum, acted upon by a lever passing through a larger space. Every one has experienced, that on opening a door or gate when near to the hinge, the force required is considerable, having little space to pass through; whereas near to the latch the task is easy, though the space is increased.

The oar of a boat is also a lever of this kind; the water being the fulcrum, the person who rows the power, and the boat the resistance or weight.

The *masts of a ship* act as levers, having the cargo and vessel as the resistance, the bottom of the vessel as the fulcrum, and the sails holding the wind as the moving power. Thus we see in smuggling-vessels and yachts, where the masts seem enormously high for the size of the vessel, that they lean over when in full sail, by pressure on the levers, in a perilous manner.

Nut-crackers, lemon-squeezers, &c. are also illustrations of this kind of lever. The two legs are joined by a hinge, which is the fulcrum; the article placed between is the resistance; and the hand is the power.

Many are the industrial purposes to which this form of the lever is applied. The common cork-squeezer of druggists is a familiar example (fig. 46); *a* is the fulcrum, *c* the power applied to the cork *b*.

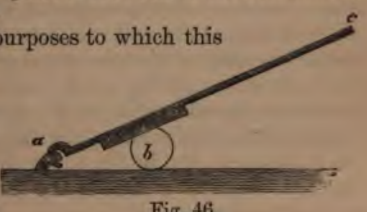


Fig. 46.

The *third* description of lever is that in which the fulcrum is at one end, the weight at the other, and the power placed between them. It has been called the *losing lever*, because the power had to be greater than the weight. The domestic implements sugar-tongs, have two long levers with a small motion near the pivot, near which the power is applied: thus they open widely to grasp a piece of sugar, and have a weak power at the ends (fig. 47).


Fig. 47.

The mechanical power of the muscles of man, acting on the bones as levers, gives us many beautiful examples of levers. The power is very great in proportion to the resistance, but the muscular attachment being near the joints or fulcra, gives a high degree of velocity to the other end of the lever, generating great momentum. In the human body sometimes the fulcrum is between the power and resistance, as the elbow is between the muscles of the shoulder and the hand with the weight; in other places the resistance is intermediate, and the fulcrum at the end, as with the hinge of the lower jaw; and in parts the fulcrum is at the end and the power intermediate, as the weight of the arm has its fulcrum in the shoulder-bone, and the power is in the muscle covering and proceeding from the shoulder.

Compound levers are arrangements of simple levers by which less space is required and power is gained, thus: Suppose three pieces of iron 12 inches long, having their fulcra placed 3 inches from the ends of each, we may calculate how much 1 stone (14 lbs.) moving power placed at the end of the first will balance at the end of the last: 9 inches to the fulcrum of the first lever multiplied by 1 stone give 9, this divided by 3 for the 3 inches at the other side of the fulcrum, gives 3 stone as the balance at its end. 3 stone, then, is the power at the commencement of the second lever, which must be multiplied by its 9 inches, giving as a result 27; this divided by the 3 inches at the other side of its fulcrum makes 9 stone as the power at the beginning of the third lever, which multiplied by its 9 inches results in 81, which divided by the three inches at the end, the total weight of the block at the other end is found to be 27 stone.

It is by this kind of combination that at railway-stations luggage is weighed; and at entrances to towns where tolls are paid according to weight, carts and waggons are drawn on to tables, and their heaviness known. By lengthening the arms on one side of the fulcrum and shortening them on the other, the force is greatly increased.

Bent levers.—These are often used for their aptitude to peculiar circumstances, and act obliquely, consequently with less effect.

The Wheel and Axle.

The wheel and axle (fig. 48) consist of the lever applied in a

modified form, by which great mechanical advantage is gained, as will be very apparent upon examination. The wheel is a series of levers, the spokes, being each one fixed on the axle.

Fig. 48.

Fig. 49.

If the axle be elongated, and the resistance to be overcome be placed upon this elongation, we have the windlass. In this the weight W (fig. 49) corresponds to the force applied at A, in an inverse ratio to the length of the arms of the lever *a*. For example, if the radius *a d* of the wheel is four times greater than the radius of the axle *b c*, we equipoise a weight by a force one-fourth of its power. If the stone W weighs 400 lbs., a force equal to 100 lbs. applied at A will sustain it in equilibrium.

The larger the wheel and the smaller the axle, the more powerful is the machine, but the greater time is taken in raising the weight.

In the common method of drawing water from a well, the handle is made to describe a large circle, and thus performs the part of the wheel described, while the axle receives the rope with the weight.

The *windlass* used on board of ships for raising the heavy anchors, and the *capstan*, are wheels and axles, the latter being upright. The head or drum has holes in it, in which are placed levers, or, as called, capstan-bars, against which the men push. They may be likened to the spokes of a wheel made moveable; the wheel describing a large circle. If a capstan-bar be six times as long as from the edge to the centre of the part on which the rope is coiled, and six men are at six bars, they will raise thirty-six times as much weight as one man could do by

his unassisted strength. Capstans are used to open and shut dock and canal gates, drawbridges, &c.

The Pinion.—If two wheels of the same size be notched or teethed so as to fit into each other, they revolve in the same time, and a weight would be raised by the axle of one as soon as the other. Where different velocities are required, and machines are to be of compact formation, then a combination of wheels is made by introducing what is called a pinion.

In fig. 50 let *b* represent a wheel and *a* the axle of another. It will be seen that the teeth placed round the edge of the one wheel work in the teeth placed round the axle of the other; but as the wheel is much the larger, it must consequently go round much slower than the axle or pinion-wheel. The teeth on the axle are termed leaves.

Fig. 50.

The mode of calculating the power gained is to divide the number of teeth in the wheel by the number of leaves in the pinion; thus if the latter has 12 and the former 144, then $144 \div 12 = 12$, the power or velocity gained.

In lathes, spinning-wheels, printing-machines, &c., wheels without teeth are made to act upon each other by means of

Fig. 51.

cords, straps, or bands; this is not to add to the power, but is useful in the regulation of a quick or slow motion. Thus in fig. 51 the wheel C drives A by the belt B.

The Pulley.

This, in its simplest form, is a grooved wheel, turning on its axis, and with a cord or rope playing round the circumference. At first sight it closely resembles the last power, the wheel and axle; but in the wheel the force has been shown to be simple leverage, the ends of the lever being the ends of the spoke of the wheel. In the pulley both the force and the resistance act in the direction of tangents to opposite sides of the circle.

A *fixed* pulley, fig. 52, with two equal weights at the ends of the rope passing over it, gives no mechanical advantage, for the weights balance; and when moved, they rise or fall through an equal space in the same time. The service to which it is applied is merely to change the direction of the power, and enables a man to stand on one spot and raise a weight which he might otherwise have to carry up a ladder. Another use is that of enabling several men to join their strength at one time in raising a considerable weight.

Fig. 52.

This pulley forms one of the most valuable assistants to the sailor, and by its means fewer men are required to do the necessary work of the ship. Now, if we fasten one end of our cord to a beam A (fig. 53), and pass it under the groove in a moveable pulley *a* to which the weight we desire to raise is attached, and then carry it over the fixed pulley *b*, we may lift a weight of one hundred pounds, by the application of a force equal to fifty pounds. To understand this, we must remember that the weight is supported equally by the beam and the power applied at *d*; but the string at *d* must move through two inches to raise the weight at *a* through one inch. Pulleys are usually compounded into a system containing two or more single pulleys, called *blocks*, and these frequently again combined in a compound system of fixed and moveable blocks, as s represented in the accompanying cut.

Fig. 53.

If the line from the fixed point is traced, it will be seen to

run under the moveable pulley *a* (fig. 54), over the fixed pulley *b*, under *c*, over *d*, then under the larger moveable pulley *e*, and passing over the fixed pulley *f*, it hangs loosely at *p*. Here we have six lines to support the weight B, and every line acting with a force equal to one-sixth of the weight; that is, if the weight is 120 pounds, each line supports twenty pounds of it, and therefore twenty pounds hung at *p* would equipoise the weight B. Supposing a man exerting a power of three hundred pounds, pulling at a string over a fixed pulley, as fig. 52, could raise a mass of stone, six feet high, in a minute; a child, exerting a power of only fifty pounds upon the compound pulley, fig. 54, would raise it to the same height, but he would require six minutes to perform the task. It cannot be too forcibly impressed upon students, that, in all mechanical arrangements, whenever we gain power we lose time;—the neglect or ignorance of this fact has frequently led to great waste of both valuable time and hard-earned money. *No power can be produced without an expenditure of force; and as we multiply the means of applying that force, we regularly diminish the rapidity of its action.* The dreams of producing perpetual motion have arisen from neglecting these never-varying laws;—it amounts to a positive impossibility that we can ever obtain a self-moving, self-supporting power.

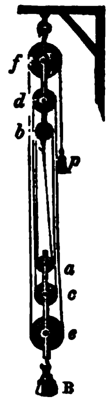


Fig. 54.

The Inclined Plane, one of the primary mechanical powers, is of use to man in many of his daily occupations. If upon the plane *c d* (fig. 55), forming an angle *x*, we place a weight *a*, the centre of gravity of the body is no longer at right angles to the plane, but along the line *y z*, and consequently it has not to support the full pressure of the weight. In lifting a body vertically from the earth, we have to overcome the full force of gravity,

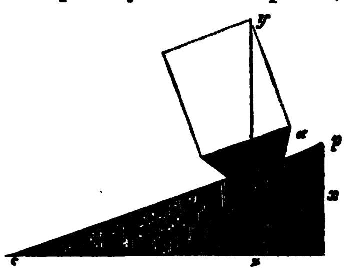


Fig. 55.

acting directly on it; but by rolling it up an *inclined plane* we are relieved from a large proportion of this force, and thus are enabled to move great weights to a considerable height with comparative facility.

The inclined plane is of constant practical application. If a man were to project a road over the summit of a mountain, beyond the force necessary to overcome the friction in drawing a heavy load up this steep incline, he must add additional force to overcome the gravity acting parallel with the inclined plane of the road, which rapidly increases with its steepness, and consequently an immense expenditure of power is necessary to draw heavy loads up such an ascent. A well-informed man would see the advantage of making the road wind around the hill, by which he would be able to move, with comparative ease, heavier bodies to the same elevation.

The Screw is an inclined plane winding round a cylinder, as will be apparent if we take a rectangular piece of paper, whose length is equal to the circumference of a glass rod, and wind it around in such a manner that the horizontal side of the paper shall form the periphery, *a b* (fig. 56), of the base of the

Fig. 56.

Fig. 57.

cylinder, the hypothenuse, as the line *a c* is termed, will wind around it in a uniformly ascending line, which line marks what is called the thread of the screw. If a triangle is continued along the thread of the screw, we have a triangular thread, A (fig. 57). If a parallelogram is continued in a similar manner around the cylinder, we produce a flat-threaded screw, B. It need scarcely be explained that by this simple form alone little mechanical advantage is gained. If we force a screw into a piece of wood, we shall find, upon removing it, that we have cut a hollow spiral, exactly fitting the projecting threads. Such is the arrangement necessary when we employ the screw to lift heavy weights, or to press forcibly upon any body (fig. 58). In either case it will be found upon examination that we have

indeed one inclined plane moving upon another, but, in order to avail ourselves of the advantages of the screw, we employ the additional power of the lever.

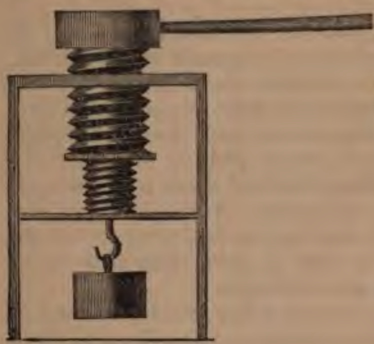


Fig. 58.

Fig. 59.

Fig. 60.

When two inclined planes are placed with their bases together, we have a triangular prism called a *wedge*, which is sometimes employed to lift enormous weights to small elevations. The largest ships in the British navy are thus lifted, preparatory to launching, by driving a great number of wedges at the same time under their keels; but this simple mechanical power is more commonly employed for cleaving wood. The power of the wedge increases as its width or back diminishes. A very important application of the wedge, or rather of a combination of wedges, has been made by Mr. R. W. Fox, in blasting rocks. A round piece of wood is divided, as shown, fig. 59, into three parts, *a*, *b*, *c* (fig. 60): the largest wedge, *b*, is to be placed upon the powder in the hole of the rock, and the two others, *a*, *c*, are dropped into their places; a small hole runs through them to convey the fuse to the bottom, which being lighted, communicates the fire, and by the lateral force of the explosion, a larger quantity of rock is rended than by any other process.

More power is gained by striking the head of the wedge with a hammer, either small or large, than by pressure, as the momentum of the blow seems to shake the particles of matter and cause them to separate. A thin wedge requires less power

to move it forward than a thick one, less resistance being offered, as in the case of an inclined plane. The power of the wedge cannot be easily estimated, as the force, number of blows, and incline have all to be taken into account. In splitting wood, the sides of the opening act as levers, and thus rend the parts in advance of the point of the wedge.

The heads of hammers are fastened on by wedges driven in at the part of the handles near the heads.

Nails, knives, awls, needles, swords, razors, hatchets, chisels, and other similar instruments are, in their operations, on the principle of wedges. A saw is a series of wedges, which act by drawing them along and pressing them on the object to be cut. When the edge of a razor is examined by a microscope, it is seen to be a saw in formation, which by being drawn along the beard, enters the hair, and thus cuts it off. A scythe acts in the same manner on grass. The saw-nature of fine edges may be illustrated by pressing the thumb against a sharp penknife; the skin is not cut, but the slightest movement of the edge across the skin immediately cuts it.

Mechanism of the Human Frame.

By examining minutely the structure of many insects, we discover formations for the purpose of fulfilling the destiny of their peculiar conditions; they are provided with saws, rasps, gimlets, needles, lancets, spades, hooks, hinges, awls, tweezers, pincers, and other tools, from which man may profitably learn the best construction of such implements.

In that most admirable of mechanisms, the human frame, we have surprising examples of economy of material, combining lightness, force, firmness, elasticity, leverage, hinges, joints, sockets, motion, resistance, security and grace, so that its description becomes an appropriate section in illustrating the principles of Natural Philosophy. In comparing the ingenious contrivances of talented engineers with the perfection of the framework of organized beings, we cannot but mark with reverential awe the vast distinction between the works of man and the works of God.

The loftiest portion of the solid human frame is technically called the *cranium*, a word derived from the Greek, signifying a *helmet*, known as the *skull*. The form of this part is that of

an arch, the best to give strength, whilst the tenacity of its material is so great as to resist shocks in all directions.

When the living principle early acts in the germ of the future human form, the covering of the brain is but a flexible

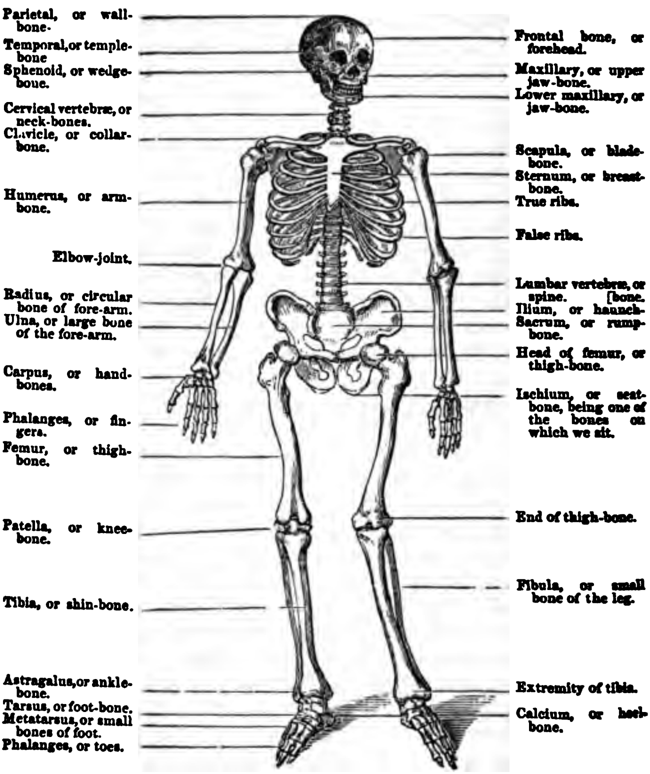


Fig. 61.

tenacious substance, which progressively developes the bony substance, like the delicate icy crystallization on water, until the whole becomes so many scales bound together by a membrane. The edges overlie each other, and the whole is soft and elastic

in early infancy; gradually, as years approach to teens, the bone hardens, and processes form for dovetailing it neatly and compactly together, which seams or joinings are called sutures. During the thoughtlessness and mishaps of youth, these joinings are not perfected; and thus when an unlucky blow is received from a fall or otherwise, its effects are dispersed at the edges of the sutures, and the vibrations being checked, the injury is comparatively small. As maturity creeps on, these minute but strong dovetailings become thoroughly and firmly united together, and the whole a hard case of bone.

On looking at the mature skull, it presents to our view, first, the *frontal* or bones of the forehead; these continue backward to the sutures, which may be felt on the crown and sides of the rounding of the head. From this, and comprising the principal part of the sides, top, and back of the head, are the *parietal* or wall-bones. Below the last-named is the *occipital* or back of the head-bone; in it is the hole through which passes the continuation of the brain into the spinal bone. The *sphenoid* or wedge-bones lie behind the orbits of the eyes, and touch the frontal and *temporal* or temple-bones; the latter contain and protect the organs of hearing, and overlie the parietal bone, being joined to it by what is termed a squamous or scaly suture.

The bone of the skull consists of two tables or layers, the one external, the other internal, separated by a spongy substance, resembling in form the cells of a marrow-bone, unequally spread, and called the *diploe*; this and the outer covering, the scalp and the hair, by their elasticity, aid in lessening the effects of a blow.

The outer dovetailed table is fibrous and tough, thus admirably suited to resist violence, to which its position exposes it; while the inner table, called *tabula vitrea*, or the glassy table, against which the delicate brain is in contact, is smooth, dense, and brittle: this latter quality would render the little projections in dovetailing easily broken asunder; therefore with that wondrous adaptation to every circumstance, the edges of the joinings are laid in contact. In the operations of man, tough wood is dovetailed, but the edges of china or glass that have to be in contact are merely laid close together.

When a man receives a severe injury on the head, it may cause such a vibration throughout the brain as to deprive him

of sense or motion; and a severe partial blow usually fractures and indents the part struck. A blow with a sharp instrument may cut into the brain itself, and not render the person insensible; while a blow with less force, but received from a broader surface, being resisted by the arched form of the head, usually cracks the bone at an opposite part to that struck. This bears a similitude to the piers of a bridge being cracked and thrust out when not strong enough to resist the weight upon the crown of the arch. The utility and power of the arch in the erections of dwellings for societies of the human family seems to have been known in the earliest history of the world. In the eggs of birds, and various seeds of vegetation, nature protects the nucleus of future life with a limy or flinty arched encasement. The brain of man, the seat of glorious mind, which directs us in our duties as to the present and future life, is carefully protected throughout existence in the hard, bony, arched case we have just described.

The *lower jaw* has a hinge-joint that permits of two motions, the greatest being in a perpendicular direction, for the purpose of allowing the mouth to open and shut, and the other in a less degree to move from side to side. Thus it has a combination of the action of the jaws of a tiger, which is a simple hinge-joint, similar to that of a pair of pincers, and a lessened lateral motion as that of sheep; one action being for the purpose of cutting, the other for grinding. The voluntary muscles of the human body are composed of a number of nearly parallel fleshy bundles, enclosed in a fine covering; these bundles consist of round hollow fibres, the diameter of each fibre being about the 400th part of an inch, containing a glutinous fluid, and threads about the 15,000th of an inch in diameter. A muscle when contracted is not less in size, but broader than when extended; in the voluntary muscles, the elasticity they possess is what renders them of such value in the functions of the human body. The temporal and masseter muscles, that move the lower jaw, are short and strong; and as they act at right angles to the line of the jaw, their mechanical advantage, or lever power, is greater than those in many other parts of the body. This gives great strength in biting hard substances, and power to crack the shells of nuts with the back teeth; as in the hinge part of a door.

The first *teeth* are small, to adapt them to the size of the

mouth; these falling out, are replaced by others, suitable to the enlargement of the frame; and finally, in maturity, the teeth of "wisdom" complete the set. Some are formed like wedges and chisels, to cut and divide substances, others for tearing and grinding. Thus we have an approximation to the pointed, jagged, and sharp teeth of the tiger, and the cutting and broad rough teeth of the sheep. The beautiful hard enamel by which the teeth of animals are covered, causes uncivilized nations to use them in various purposes of rude manufacture, while in our own country the tooth of a dog was formerly used as a polishing tool by bookbinders.

Fig. 62.—A magnified view of Tooth structure.

1. Longitudinal section of part of a superior canine tooth, exhibiting general arrangement, contour markings; slightly magnified. 2 and 3, portions of same, highly magnified, showing the relative position of *bone-cells*, cementum. 2. Dentine fibres, and at 3, the commencement of enamel. 4. Dentine fibres decalcified to show tubules. 5. Nasmyth's membrane separated and the calcareous matter dissolved out with dilute acid. 6. Cells of the pulp lying between it and the ivory. 7. A transverse section of enamel, showing the sheaths of fibres with their contents removed (magnified 300 diameters).

Next to the head in importance to the functions of sensation, and as important as the brain itself to the continuation of life, is the spinal marrow. In the grand design of the framework of the human body, not only is there a powerful protection afforded by the formation of the spinal bony column for the nervous matter which fills its cavity, but while it sustains the

head, and bends to the motions of the body, it also is the connexion of the higher and lower parts of the skeleton.

Behind the bones that keep the body erect a spinal process projects, from which the common name given to the column of *spine* is derived; the separate bones of which it consists are called vertebræ. In form the spine resembles an italic *f*, the lower end tapering off; joining this root part it curves inwards, and the bones of the vertebræ here are the largest, and, somewhat like the stem of a tree, decrease upwards. Twenty-four distinct bones constitute the true or moveable vertebræ. The part we designated the root is composed of a triangular-shaped bone called os sacrum, and another os coccygis.

The bones are nearly cylindrical, with a perforation behind for the spinal marrow, and have a projecting spinal process; as well as two other processes at the top and two at the bottom of each vertebra. The first five large vertebræ are called lumbar, that is, pertaining to the loins, above which are twelve called the dorsal or back vertebræ, to which are attached the ribs, forming with the breast-bone the part called the thorax; the seven piled on the last-named are called cervical, belonging to the neck,—these curve first in a forward direction and then recede in the upper back part of the head, giving that graceful form so admirable in the neck; the highest but one of these, from a remarkable toothlike process it possesses, is named the vertebra dentata; and the topmost one, that immediately supports the head, the atlas; and justly so, as it bears upon it the individual world the mind creates: from the ideas that form the links of the mental chain organized beings recognize themselves from each other; when it is broken, the living mass of matter is in that pitiable state called insanity; and when annihilated, by the flight of the imperishable soul, there is the darkness and vacuity of death.

Having piled up this wonderful column from the foundation, let us now see how inimitably it is adapted to the purpose of its design. Beyond that of protection to the life-constituting cord of matter, it has to possess elasticity, to prevent any jar upon the brain, and therefore to let the head be borne with the ease of a carriage upon springs; it has to be flexible, that the body may move in all directions; firm, to support the upright position of the body, a fulcrum to the muscles, a prop to the ribs; and it has to possess strength, that weights may

be borne on the shoulders and back. It is related of Topham that he lifted by his shoulders three hogsheads of water, weighing 1836 lbs.;—wonderful, then, is the mechanism of this column!

First, we may note the manner of the head being placed on the spine. There are two prominences at that part of the skull called the occiput, which are received into two corresponding cavities of the atlas; by this the head can move forward in the manner we do when we nod, but the atlas-bone turns horizontally round the tooth-like process of the next bone, the vertebra dentata, and thus the head moves from side to side; therefore there is the up-and-down and rotatory motion effected by these two bones. But as these motions are limited and man requires more, the flexibility of the spine comes to our assistance, and thus we can freely move the head in any direction. Now, as the joint of the head and the spine is not quite in the centre of the bottom of the skull, the head, unsupported, would drop forward; to prevent which in the living subject there is a strong ligament coming from the cervical vertebræ, and fastened to the bottom part of the skull. When in a sitting position, and sleep overcomes us, the muscles relax and the head drops forward.

The contrivance to give elasticity to the spine consists of a soft, firm, elastic substance, about half as bulky as the vertebra itself, that is inserted between each vertebra; this in some parts is thicker before than behind, so that when we stoop forward, it is compressed, and the surfaces of the bones of the vertebra become more parallel to each other than before, and no opening between takes place; then, when the pressure is relieved, the elasticity, like a spring, sends the body again into an erect position; while any danger that might arise from a shock at the lower part is removed by this body of elastic substance, which prevents the hard and unyielding bone, or double rings, from coming in contact.

The column is accurately described as a chain, from its firmness and flexibility. The number of the joints give the pliancy it possesses, which is greater in the loins, being more required in that part than in the back where firmness is necessary, and greatest of all in the neck, on which has to move that part containing the organs of sight. Then to preserve uninjured the spinal marrow, and yet to allow of free movement of the

parts containing it, the processes and projections of the vertebræ so lock in with and overlap each other, as securely to prevent the slightest derangement of the bones, and the free unharmed continuation of the delicate cord. Though we may bend the back to a great extent either backward or forward, yet its many links prevent any part from being overstrained. We know that if we give considerable inclination to a cane, that although, on the whole, there is a great bend, yet each individual part is only bent to a small extent. To add still further to the compactness of the elasticity, a ligamentous substance joins the roots of the spinous processes to each other. In fact, the whole is really stronger than if a solid column of bone had been inserted, so perfect and far-seeing is the design of the great Architect of the human frame.

The contortionists who exhibit their feats in the streets and public places of amusement, rarely injure their spines; and diseases of that part are rare, excepting those brought on by a false and pernicious system of education. Keeping the body too long in an upright position, and not allowing free scope to the excess of animal spirits in the young, is frequently the cause of spinal distortion, as well as the bandaging of the youthful frames of females, with bars or splints of steel and whalebone, to distort them from the comeliness and elegance of nature's outline, is distinctive of an obliquity of intellect and ignorance of beauty that is ridiculous and culpable. Pity the Chinese ladies, indeed! when pains are taken to pervert the beneficent laws ordained by an unerring Godhead, to render a creature divinely perfect a deformed object throughout life—to entail frightful diseases by inhuman fashions—to invite an early tomb for a loved and loving offspring. Dr. Arnott truly remarks—"It would be disgusting to see an attempt made to improve the strength and shape of a young racehorse and greyhound, by binding light splints or stays round its beautiful young body, and then tying it up in a stall; but this is the kind of absurdity and cruelty which has been so commonly practised in this country towards what may well be called the most faultless of created things."

Forming a powerful bony elastic exterior to a hollow interior is accomplished by the *ribs* attached to the spine. The ribs are long, curved, flattened narrow bones attached at the back to the spine, or that part called the dorsal vertebræ, and their

transverse processes being joined in front by an elastic cartilage affixed to the sternum or breast-bone. They are twelve in number; the upper seven are called the true ribs, and the lower five, the cartilages of which do not reach the sternum, are named the false ribs. Greater security to these bones is ensured from their not being straight, but hanging downwards like the lower part of the sunshade ladies affix to their bonnets; but there is another advantage: in the action of filling the lungs with air, the ribs rise up and enlarge the space for the reception of the breath, while the great elasticity of the cartilage aids this important action, and also gives way to any sudden blow. This could not be so well effected, if instead of the cartilage there had been a bony joint. In stooping forward or on either side, the elastic substance readily yields, and recovers itself by its spring. The muscles, which have their origin on the ribs, and their insertion into the bones of the arm, afford us an example of action and reaction, being equal and contrary. When the ribs are fixed, these muscles move the arm; and when the arm is fixed, by resting on a chair or other object, they move the ribs. This is seen in fits of asthma and dyspnœa (difficulty or shortness of breathing). As age advances, the cartilage becomes bony, and hence less suitable for any violent exertion of the respiratory organs; this should lead us to be tender of those who have reached "the evening of life;" and truly are men philanthropists, who would provide ease and comfort, after a certain age, for those who have, unprofitably to themselves, spent the energy of their prime of life in labour.

The *shoulder-joint*, which enables us to exert great strength, and has such freedom of action, is formed by the round head of the shoulder-bone, called the humerus; this is placed in a shallow cup of the blade-bone or scapula, and together they form a ball-and-socket joint; there are two strong bony projections above and behind that keep it in its place, and the ends of the bones are enclosed by a thick and strong membrane, so that dislocation is provided against. The two objects of strength and extent of motion are thus carefully secured; and to add to the latter, the shoulder-blade holding the round head of the arm-bone slides about upon the hollow of the chest, held, however, within bounds by a strong ligament to the breast-bone.

The *clavicle* or collar-bone is of a slightly arched form,

and has attachments to the breast-bone and blade-bone in a shallow cavity. It is of great strength, but from its situation liable to accidents. On it, and the bed of muscles near, great burdens are supported in many industrial occupations.

At the upper and back part of the chest is the *blade-bone*; this, to the mechanist, is an example of lightness combined with strength. When the wheelwright desires to give the best form to his work, he makes the felly, the spokes, and the nave strong, and bends the spokes inward, in a manner termed *dishing*; and thus is the blade-bone constructed, slightly arched, with its principal strength at the edges and spines, and other parts thin and light. This simple and incomparable mode of construction is found generally in animals possessed of bony frameworks.

Joined by a hinge-joint at the elbow is the *arm-bone*, or humerus to the ulna or *fore-arm bone and radius*; motion here is only a backward and forward one, being restrained by strong ligaments from any lateral motion; thus it is a mere hinge, and can only be considered as a lever, as the muscles that move this part are long, very much slanted, and have to act near to the fulcrum or centre of motion. They have consequently to be very strong. In fact, it is calculated that the muscles of the shoulder-joint, when lifting, put forth a force of 2000 lbs. As, however, there is ever wisdom and goodness in the works of Providence, what is lost in leverage power of the arm is gained in velocity; and thus by rapidity of action we make up for the sacrifice of power. How lost should we be, were the muscles different, formed for giving only immense strength, and accompanied with slowness of movement! We then could not so speedily protect ourselves by raising the hand and arm, and from many of our present enjoyments we should be debarred.

The *wrist* and *hand* is divided by anatomists, first, into four bones; these, with the arm-bone, called the radius, form the joint: the first four bones are joined to other four, and these eight bones constitute the wrist; from this part proceed five bones, which may be felt at the back of the hand; joined to these are the three bones in succession of each finger, and the two forming the thumb. The turning round of the hand and wrist is effected by the radius-bone of the arm revolving round the ulna-bone, and of course the hand with it, without the wrist-

joint moving. [It is obvious that this important bone derives its name from its power of motion in radii, or circles.] Not only do we gain flexibility and power by having a number of small bones in the hand and wrist, but also numerous shocks to which it is subject are deadened before reaching the higher parts of the arm. At the wrist-joint a strong ligament passes around it, by which the tendons that proceed from the arms for the movement of the fingers are bound together; were this not the case, we should have a hand about as shapeless as a hoof, and not much more useful; whereas we now not only have grace and beauty by this arrangement, but also strength with combined motion, and delicacy in partial motion, as of the fingers alone, instead of weakness. The mechanism of the hand is one worthy of careful study and deep reflection, being one of the principal sources of man's pre-eminence in creation, and aided by reason, displays in distinct characters the marvellousness of the works of the Divine mechanic.

As observed in a previous chapter, the nearer a weight is to the fulcrum, the greater the amount that can be borne; from experience we know we can sustain a weight on the arm near the joint, that we could not hold in the hand of the outstretched arm.

Fig. 63.

In the annexed diagram, *a* (fig. 63) is the fulcrum or point of resistance, *e* is the weight pressing downwards, and at *b* is the muscle that draws upward. Now if a two-pound weight be placed one inch from the fulcrum of the joint and then moved to the centre of the hand, and say the distance it is removed is fifteen inches, then to find the force with which the weight will press downwards, the distance must be multiplied by the weight. In this example, the force that will press downwards will be equal to thirty pounds.

To support the spinal column and unite the two columns of locomotion, the legs, there is a broad, light, hollowed bone called the *pelvis*. The two haunch or hip-bones are large, and when no strength can be gained by its presence the bony substance is omitted. They present a broad surface, and

are so placed as to form an inverted arch; a form combining the greatest strength with economy of material. The hollow receives the lower part of the abdominal viscera. To the upper edge of the pelvis is firmly joined that part of the spinal column named the sacrum. Powerful muscles are attached to the bone, the lower portion of which, forming two large projections, support the body when in a sitting position. The bones are connected by cartilaginous surfaces and large ligaments so strongly, that the whole must be destroyed before any one part will yield.

The *hip-joint* is an admirable adaptation of the ball-and-socket joint: a large rounded head-part of the thigh-bone fits into a deep cup of the haunch, and is prevented from slipping out by a strong and deep cavity. From the bottom of the cup and around the edges, cartilages and ligaments arise, which give security to the joint, and resist any force likely to displace the bone, while at the same time it allows a free motion to the foot, and ample range to the various actions of the leg.

In the *thigh-bone* the rounded head stands off from the shaft, but the projection is so placed that the strength and weight are thrown upon the shaft. The thigh-bone bends forward in an arched manner, and has knobs, to which are attached the powerful muscles of the leg; over the fore-part of the bone the action of the muscles is great, and the curve of the bone consequently gives a strength which it would not have had, had the bone been straight.

The *knee-joint* is composed of three bones, curious in their arrangement, at the same time perfect for the purposes intended; the termination at this part of the thigh-bone appears of a rounded form, resting on a shallow cup; it implies no strength, from the manner in which it is placed. To make up for this there are two strong lateral ligaments, and a ligamentous rope within the cavity of the joint. It is a singular property of the ligaments on the inside of the knees, that they become stronger the greater the strain upon them. The duties thrown upon the ligaments here increase the great elasticity of the limb so often called into use in violent quick exercise, and is another of those arrangements which are so inimitably suited to give advantage to man's position in the scale of organized beings.

The large muscles of the front of the thigh are attached to

the leg below the knee, and in their passage have to pass over the part where the joint of the knee exists. Before they arrive there they are contracted into a tendon, and become inserted into the bony structure in front of the joint; this bone, called the patella or knee-pan, is a valuable protection to the joint. By this arrangement a mechanical advantage is gained, the centre of motion being increased in distance from the pulling power.

The bones of the *leg* much resemble those of the arm: the largest is called the tibia, leg, or pipe; and the smaller the fibula, or brace; they are angular, as a preservation from injuries, and affording a considerable surface for the attachments of the various muscles. A large flat portion of the tibia is covered only by skin, and is named the shin.

Between the two bones of the leg just named, which project at each side to form the *ankle*, is received the great articulating bone of the foot called the astragalus; when the foot is raised, this joint is fixed, and as the body comes down, the support is thus firm and steady to bear its weight. The tendons are bound down by a ligament passing over them, as at the wrist; were it not the case, the foot would more resemble in shape that of an elephant's, and although the tendon would have greater power to draw up the toe on which it acts, yet its rapidity of movement would be lost. One of the tendons passes along a groove under the bony projection of the inner ankle, exactly as we place ropes over a pulley.

In the *foot* there are thirty-six bones; of these, seven comprise the tarsus, or part that reaches from the heel to the middle of the foot. The heel, by projecting backwards, forms a powerful lever, on which the muscles of the back of the leg, terminating in the Achilles tendon, act by lifting up the body and throwing its weight on the toes. When the muscles of the calf are naturally small, as in the black race, the length of the lever of the heel is increased, and thus a provision to make up the other deficiency. Next to the tarsus are five bones placed parallel to each other, called the metatarsus, from which proceed the three bones of each toe; the great toe has only two. As the foot comes to the ground, the heel touches first, next the balls of the toes, then it rests on a beautiful arch; the surfaces of the bones are protected by a layer of cartilage placed between each, and they are lubricated with an oily

fluid: thus, in consequence of the number of joints and the nature of the surfaces, the whole is rendered completely elastic and fitting for the various shocks in walking, running, and leaping; for what can we conceive permitting of a more easy springing carriage than that of an elastic arch? If a small arch was built up of wedges having pieces of india-rubber placed between each, it would resemble the mechanism of the foot.

In walking, we sway a little to one side, then to the other, as the weight of the body is moved from one foot to the other; but were the leg inelastic, as when a wooden one has to supply the place of a natural one, the lower part would have to be advanced in a kind of half-circle; from a slight bend of the knee, and the contraction and lengthening of the muscles, the leg is moved straight forward, and thus the body more easily and steadily progresses.

Even this cursory and popular glance at the mechanical arrangement of the framework of the human body must strike all with gratitude and lead us to see we are "fearfully and wonderfully made;" still there are other points worthy of attention, which have not yet been noticed.

A teacher of medicine in the sixteenth century was accused of promulgating doctrines contrary to a belief in the existence of a God, and sentenced to death; he repudiated the charge, and picking up a straw, said, "If there was nothing else in nature to teach me the existence of a Deity, even this straw would be sufficient." This beautiful and simply expressed truth did not perhaps strike his blinded bigoted judges in the manner it ought to have done; let us put aside many other important particulars, and merely examine the mechanical construction of a straw. It is well known that if a beam resting on each end bends in the centre, the atoms of matter in the outer part of the curve are slightly separated and only held together by the general tenacity of the substance, and that the atoms of matter in the inside of the curve are driven closer together, while the atoms of matter in the centre of the beam, called scientifically the neutral axis, lie truly neutral, and may be removed without much damaging the strength of the beam. This shows us that a hollow piece of wood would be about as strong as a solid piece, and is one argument in favour of a straw being made in this manner. But if the material composing the stalk of corn were formed into a solid, it is palpable

to the commonest understanding, that it would not have strength enough to support the weighty head as it does so gracefully and securely. On this point it has been proved by Tredgold, that when the inner half-diameter of a hollow cylinder is to the outer as seven to ten, it possesses twice the strength of a solid one of the same weight; arising from the substance being further from the centre, and therefore resisting with a longer lever. This, then, is conclusive of the wisdom of a hollow form given to the straw; and from such reasoning originated the valuable improvement of hollow tubular bridges, resulting in the majestic structure across the Menai Straits. Another advantage which is important is the lightness of the tall column of straw and the economy of material, whilst its height allows it elastically to bend to the passing breeze without breaking; each part but gently feels the power before which it has to bow, and consequently it rises again uninjured. Besides these circumstances mentioned, the cornstalk is formed with an outer surface of a hard material comparatively with that of the inside, and in many vegetable stems their forms are ridged, angular, and fluted. In describing the straw we have been generally describing the structure of the bone of the human frame; in one particular it differs, that is, as to rotundity; it possesses a hard outside in many places, more especially in the teeth and spine; the humerus has ridges to give strength, and it is tubular; the whole exemplifies lightness and economy of material, as does the straw. The hollow of the bones is occupied with fine membranous cells, not communicating with each other, but filled with an oily substance called marrow. In some of the extremities of the bones which are expanded to increase the extent of surface about the joints, there is a thin compact substance that looks like a kind of honeycomb, as we see in the broken bones of animals placed on our table as food. In the oblique part of the thigh-bone these are found to converge to a point in the shaft, as if supporting the parts projecting from the centre of gravity. Hard as is the surface of a bone, it is penetrated by minute vessels which convey nourishment to make up for waste of substance and to renew its living material; for the law of nature is, that during our passage from the cradle to the grave every atom of us shall be continually changing. These bony cells, called *cancelli*, exist in the broad flat bones; their outer surfaces, named plates or

tables, being strong and hard. The tough elastic substance cartilage acts as a pad, defends the bones against friction, fills up irregularities, giving a smooth gliding surface of a milk-white pearly colour, always where firmness, pliancy, and flexibility are needed in the body; in the spine and foot these qualities so neutralize the effect of concussions, that neither the brain nor spinal column suffers as they would if they were absent. The weight of the upper part of the body on the cartilages of the spine during the day compresses them, so that a person is taller on rising in the morning than on lying down at night. This compression has been found to be in some instances as much as an inch. The joints are tied together by strong unyielding cords called ligaments, which have a tenacity hardly to be found in any other substance. These hold the bones in their places, and restrict their motion. The cartilaginous surfaces of the joints, to aid ease of motion and obviate friction, are lubricated with an oily fluid, vulgarly known as joint-oil, which is secreted and confined to those parts by a very delicate membrane, called the synovial membrane.

Bundles of minute fibres are joined together and form a muscle; their cohesion is maintained by vital power: thus a powerful living muscle is weak and easily torn when dead. According to the intended action of particular joints, so are muscles placed to aid them by their mechanical power. The contraction of a muscle is towards its centre; hence it is so placed and shaped as best to contribute to this mechanical purpose; in some instances there is an increase of tendons to a muscle, in others an increase of muscle to a tendon. One of the muscles of the eye-ball is a perfect pulley, and moves the eye in a direction contrary to that in which the force is applied. In fact, the whole of the muscular system is a beautiful adaptation of power to the purposes of life.

The size of the muscles depends much upon their exercise; thus the arm of the anchor-smith is thick and powerful from being brought into constant and violent action; the leg of the ploughman is a mere straight shank from his restraining the action of the muscles by thick unbendable laced boots; thus the bluff brawny-shouldered man has calfless legs, and is said to be spindle-shanked. The opera-dancer, who practises "the poetry of motion," has well-developed muscles from incessant exercise of the feet and legs.

The strength of muscles by exercise is exemplified in the person of every one in reference to the arms, as from the habit of using more constantly the right hand the right arm is much stronger than the left. So negligent have society generally become, and so pernicious their fashions and systems of education, that diseases arise from the inaction and pressure on this grand contrivance of leverage for motion. All exercise should be moderate, gradual, and regular, like the training of a race-horse, but not excessive. When a prize-fighter trains, he partakes moderately of everything, eats underdone beef-steaks with an allowance of bread, and thus raises the power of his muscles to the utmost pitch for the occasion; but were he to continue this system, disease with its accompanying prostration would ensue. Dr. Arnott observes, "As animal power is exhausted exactly in proportion to the intensity of force exerted, there may often be a great saving of it by doing work quickly, although with a little more exertion during the time. Suppose two men of equal weight to ascend the same stair, one of whom takes only a minute to reach the top, and the other takes four minutes; it will cost the first little more than a fourth part of the fatigue which it cost the second, because the exhaustion is in proportion to the time during which the muscles are acting. The quick mover may have exerted perhaps one-twentieth more force in the first instance, to give his body the greater velocity, which was afterwards continued; but the slothful supported his load four times as long. The rapid waste of muscular strength which arises from continued action, is shown by keeping the arm extended horizontally for some time: few can continue the exertion beyond a minute or two." Nevertheless the fakirs of India, the country where bigotry overpowers nature, will stretch out an arm and hold it in that position until the muscles become rigid and wasted, and the arm immoveable.

The power of the muscles of man is far beyond that of any animal approaching his size; there are instances of the capability of endurance of muscular fatigue and exertion almost incredible, and never equalled by quadrupeds. We have referred to the feat of Topham; and there was that of Carr the blacksmith, who lifted up a large anchor of a ship and carried it over the sands at the sea-shore to his workshop,—a weight that would have broken the back of a horse. This same man

on one occasion laboured at his fatiguing employment during upwards of ninety hours without cessation. In consecutive days' journeys a horse cannot compete with a man; the former becoming exhausted, while the latter seems to add to his powers of continuance. The fatigue of walking a thousand miles in a thousand hours, uninterruptedly, and part of that backwards, is an act showing a continuance of muscular exertion that no animal could sustain; and we suspect it would be difficult to meet with a quadruped, with all its advantage of length of leg for progressive motion, that could walk ten miles in one hour and twenty-two minutes;—yet such feats have some men delighted in accomplishing.

Mechanism of other portions of the Animal Economy.

There are other parts of the human frame destined to perform hydrostatic and pneumatic operations, having pipes, valves, capillary tubes, and other wonderful arrangements for carrying on the vital principle that animates the body, and to which a few pages may be usefully and appropriately devoted.

We have noticed the teeth cut and grind the food by a power derived from the nerves; the muscles move the jaws, which become powerful levers: the tongue moves the food about, and places it under the grinding teeth until it is sufficiently reduced in size to swallow: the lips prevent its falling out. While the muscles are acting on the jaws, they also compress glands situated between the ear and lower jaw-bone, and beneath the tongue: from these proceed minute ducts to the middle of the cheek rather nearer to the ear, others open at each side of the membrane which ties the tongue down to the inside of the lower jaw: from these a watery fluid exudes called saliva, which softens and mixes with the food, that it may the more easily glide down the throat. The tongue, moving upward and backward, rolls the aliment into that part seen on looking at the back part of an open mouth, which is named the pharynx: here are a number of muscular fibres, which, by contracting, force the food towards the stomach. The pharynx is, however, deserving of further notice. On looking upward, may be seen two large openings leading to the nostrils. Between these and the entrance from the mouth is the soft palate, a kind of fleshy moveable curtain, and in the middle of this is a pointed little lump, which projects outward, named

the uvula. On each side there are bodies of a glandular nature, whose office it is to secrete a lubricating fluid, to facilitate the easy passage of the pasty mass of aliment; these are the tonsils. The larynx, or commencement of the windpipe, is placed before the pharynx just at the root of the tongue; near this part is the glottis, in front of which is a cartilaginous valve, standing perpendicularly, designated the epiglottis. We all know the great sensibility of the membrane of the windpipe, and that if the slightest morsel of food or other matter touches it, from its irritable nature a convulsive fit of coughing ensues; and thus the folly of laughing or talking when eating meets with a painful punishment: yet every particle of food has to pass over the glottis, and this leads us to the mechanism of the art of eating. When we perform the act of swallowing, the tongue moves backward, at the same time the windpipe is raised upwards, and the epiglottis descends, which effectually covers the opening; while the food, having reached the pharynx, presses upon it, and thus keeps it still more securely closed. The aliment having glided past, the tongue returns to its former position; the windpipe is drawn down, the epiglottis is again erect. and there is a free open passage for breathing. This beautiful simple mechanism acts from the motion of the parts themselves, independent of the will of the person or animal. But during this time the moveable curtain has been assisting, for it closed over the nasal openings, so that nothing should pass in that direction; and were anything rejected by the stomach, it is thrown, in such painful circumstances, with force against that part, and would thus find an exit; but it is very difficult to force this passage, from the elevation of the soft palate over the openings.

The windpipe is divided into three parts, called the larynx, the trachea, and the bronchi. The larynx, we have said, opens at the root of the tongue, and is the upper part of the trachea. Five pieces of cartilage compose this important piece of mechanism; the largest, named thyroid, consists of two irregular quadrangular pieces which unite at an obtuse angle in front, and project at the fore-part of the neck. This projection, which is strongly developed in men, the vulgar believe or say originated in the moment of hesitation of our first progenitor before swallowing the forbidden fruit, which, in an evil moment, he had been induced to take, and was to lead to sin;

hence it is named *pomum Adami*, or Adam's apple. Several ligaments are attached to the cartilages, and between two of them, the vocal chords, is a chink or cleft for the passage of the air; through these we force the air, and the voice is produced. The lining of the larynx is softened by a plentiful supply of mucus, which defends it from the cold or heat of the external air. It is perfectly pliant to the movements of the neck. One of the cartilages, cricoid, has the shape of a ring with a seal in it: the broadest part, being placed behind, connects two pyramidal portions of a cartilage, arytenoid, whose movements alter the size of the aperture of the glottis, and slacken or bring together the vocal chords; and thus produce all the beautiful modulations and tones of that most divine harmony of which the human voice is capable.

The trachea extends to the bronchi, and is a tube of from five to seven-eighths of an inch in diameter; it is in the middle of the fore-part of the neck, and before the gullet. If we take some hoops, cut away about the fourth part, then taper the ends, lay a thick part on the thin part of the other, and thus build them up, attaching them to each other by an elastic membrane, we form a pliant pipe, and one having a resemblance to the trachea. It is very sensitive, and lubricated with mucus. The bronchi are a continuation of the trachea divided into two separate tubes branching off to the two lungs,—the right is the largest and the shortest; these divide into smaller and smaller branches, and ramify as air-cells in every part of the lungs; it is the inflammation of these fine tubes, or their disorganization, that creates the distressing and often fatal malady called bronchitis.

To return to the food which had got as far on its journey as the muscular tube, called the gullet or œsophagus, from whence it passes downward to the stomach; this is a muscular membranous bag somewhat in the shape of the Scotch bagpipes, larger at the left, and decreasing in size to the right, curved or arched at its exterior, with two openings, and capable of holding from five to eleven pints. The inside bears a resemblance in structure to velvet.

The effect of the folly and impropriety of indulging too much in any food that is gratifying to the taste may here be noted. The abdomen is rendered tense and projects; and by

its enlargement the part called the diaphragm or midriff, which divides what is termed the superior from the inferior parts, or the cavity of the chest from the abdomen, is forced upward into the chest, which allowing less room for the action of the important functions there performed, the breathing becomes difficult, and is hurried, thus rendering speech often what is popularly termed thick; by the fulness of the abdomen the blood is driven to other parts, and often ascends to the head, where, collecting in the arteries in too great an abundance, it produces that fatal malady, apoplexy.

After the food reaches the stomach, a liquid oozes out of the internal glandular surface, called the gastric juice. This juice will dissolve almost any substance, the casing of seeds forming an exception; it reduces the food into a mass, chyme, which next passes a contracted ring, the pylorus, or keeper of the gate (this prevented its egress until the gastric juice had performed its duty); it then enters the smaller intestine, the duodenum; journeying onward it receives a mixture of bile and pancreatic juice from the liver and pancreas; the milky fluid known as chyle is now produced, and absorbed by lacteals, or milk-tubes, which convey it to a vessel near the heart, where it finally mingles with the blood and nourishes the body. The distance it travels is about that of six times the length of the body.

The intestinal canal is smooth in its outer surface, and supplied with a slippery fluid, whereby it glides about with perfect ease. The expulsion of the refuse from thence takes place by the elasticity and muscularity of the coats, which, by successive contractions of its fibres from the higher to the lower parts, act by a gentle pressure around the tube, carrying onward the contents. The abdomen may be considered as a vessel full of liquid, on which there is a pressure in all directions, increasing with the depth (see Hydrostatics), and increased also by the action of the surrounding muscles which form the sides of the cavity.

Straining, or strong action of the abdominal muscles, and therefore pressure on the abdominal contents, occurs with almost every bodily exertion; for the abdominal muscles are the antagonists of the great muscles of the back and about the spine, and must always come into play with them, to give firmness and rigidity to the trunk of the body. This may be

seen remarkably in the actions of lifting, running, wrestling, &c. As the abdominal muscles cannot act in a continued way and strongly, unless the ribs, from which they arise, become nearly fixed, during exertion the ribs are supported by the intercostal muscles, and by the air in the chest, confined for a time by the closure of the air-passages in the throat; hence there is generally compression in the chest also when the abdomen is compressed, and the blood is squeezed towards the extremities from both cavities at once. It is important to remark here, that in what are termed the strong actions of the chest, as coughing, sneezing, blowing, &c., the abdominal muscles are the great agents. By pulling down the ribs to which they are attached, they narrow the chest; and by pressing the abdominal contents, and thus raising up the diaphragm, they shorten the chest.

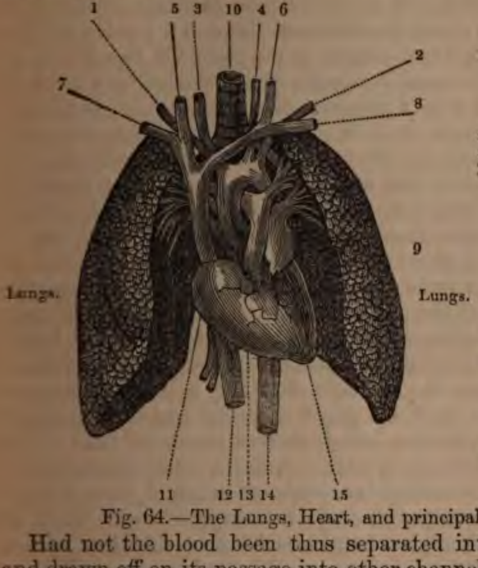
We have proceeded as far as the formation of food into a substance which replenishes that important fluid the blood, the circulation of which is a subject of interest. That portion of the scientific world pursuing the ennobling study of anatomy owes its progressive impulse to the grand discovery of the circulation of the blood by that renowned Englishman Dr. Harvey, who announced the fact in 1628.

The arteries and veins are arborescent over the entire body; springing from a root, the heart, the thickly-placed branches and twigs of which ramify through every part.

The position of the lungs, heart, and principal vessels of the human body may be more easily comprehended from the following illustration.

Arising from the left chamber or ventricle of the heart is the great arterial tube called the aorta, which dividing and subdividing into smaller and smaller tubes, until the termination of some are lost in their very minuteness, they pervade the furthest extremity of the living body, carrying in their canals the life-inspiring bright-red blood which gives warmth and replaces the waste going on in the system. When these services have been accomplished, the extreme distance is attained, and the vigour and ruddiness of the fluid becomes a deadened purple hue; then the vessels are reflected back, and form so many minute venous streams, which, joining into larger channels, ultimately reach the part from whence we started, the heart, there once more to undergo purification and addition: thus the

arterial and venous systems become joined, but each performs a separate function; the one carries onward the fresh red stream, the other returns the exhausted, purple, thickened liquid (fig. 64).



1, 2. Subclavian arteries, giving off blood to the upper extremities, arm, &c.
3, 4. Carotid arteries.
5, 6. Jugular veins.
7, 8. Subclavian veins, carrying the blood back to the heart.
9. Pulmonary artery sending off branches to each lung.
10. The trachea or windpipe.
11. Right auricle of heart.
12. Inferior vena cava, or large inferior vein.
13. Right ventricle of heart.
14. Aorta descending.
15. Left auricle of heart.

Fig. 64.—The Lungs, Heart, and principal vessels.

Had not the blood been thus separated into little streams and drawn off on its passage into other channels, but proceeded straight down to the lowest extremity, we may imagine what a weight would have been felt at those parts from the amount of fluid pressing outward, which increases about half an ounce every square inch. After a meal the action of the heart is accelerated, and still more so during bodily exertion or mental excitement; it is slower during sleep. And it appears that the frequency of the pulse is in some degree regulated by the same causes; in the morning it is more frequent, and becomes gradually slower as the day advances, decreasing more rapidly towards the evening and from fatigue. The standing and sitting position affect it in a similar manner; and food, like that of change of posture, more so in the morning than in the evening.

The heart lies towards the left side; the broad part towards

the right and backwards, and the pointed part towards the left, forwards and downwards. The flat surface rests on the midriff or diaphragm, and therefore, as this part moves upwards and downwards in the act of breathing, it raises and lowers the heart. The pointed part is opposite the cartilage of the fifth and sixth left rib; and in this part there is a portion of the left lung removed, as if to give ample room for the action of the heart. It is encased in a bag, and surrounded by a fluid to give moisture and ease of motion. When taken from the body, the heart weighs from ten to fifteen ounces, and is larger in proportion to the body in the young than the old subject, and frequently smaller in tall and strong men, than in those of ordinary height and moderate muscular powers. The heart consists of two parts closely connected together, each of which has two cavities: an auricle, or membranous bag, placed at the mouth of the veins; and a ventricle, or strong muscular chamber, placed at the orifice of the artery. When the purple fluid returns, it is poured into the right auricle of the heart by three veins; the nutritious portions of the food are collected by absorbents into the thoracic duct and a large vein, and mingled with the blood as it passes in an agitated state through the heart. The auricle, which derives its name from some supposed resemblance to a dog's ear, has a small fringed process, and its inside surface is smooth and polished, having some muscular fibres arranged so as to be compared to the teeth of a comb. Next through a large round orifice, the blood enters the right anterior or pulmonary ventricle, and isprevented being driven back by a valve; it is divided into three pointed portions, having numerous tendinous strings, by which it contracts. It may here be observed, that the ventricle is a strong muscular cavity with power forcibly to propel the blood by contraction, while the auricle is a mere supply-tank to fill the ventricle as it becomes empty. The blood passes next to the arterial orifice of the ventricle, where there are three valves of a half-moon shape to prevent any retrograde movement; and being now in the pulmonary artery, it is emptied into the lungs, where it is brought into contact with the very fine and delicate bronchial capillary tubes; here it mixes with the oxygen of the air, which is drawn in by the act of breathing, and becomes vivified scarlet arterial blood. Four pulmonary veins, two of which belong to each lung, now pour the freshened blood into

the large left or posterior auricle, situated at the upper or back part of the heart; here, again, is a valve, the mitral, likened to a bishop's mitre; the blood is now fresh, red, and warm, ready to commence its tortuous journey, and give life, energy, and food to the entire body. The left ventricle is thick and strong, like a solid mass of flesh, having to drive the blood up the aorta, also guarded by three semilunar or half-moon valves, and send it to the remotest parts. The aorta is the great tube from which all the arteries branch off and receive their precious supply.

The lungs are spongy bodies, the vessels and thin membranes of which are chiefly formed into cells covering a surface equal to about thirty times that of an ordinary sized man. Into these the air we breathe being received, the oxygen is taken up by the blood, and the other parts rejected and returned. As the chest expands the air rushes in, and is again expelled by its contraction. The lungs are divided into five parts or lobes, three lying on the right side of the chest and two on the left: these are enclosed in a bladder-like substance named the pleura. The air rushes in among the minute and thin vessels containing the blood, and every part is penetrated by it, and every atom of blood chemically changed; the black impure blood instantly becomes bright scarlet.

The principal force provided for constantly moving the blood through the vessels, is that of the muscular substance of the heart, assisted by the elasticity of the walls of the arteries, the pressure of the muscles upon the veins, and the movements of the walls of the chest in respiration. If an upright tube were connected to an artery, there would usually be found a column of blood about eight feet above the level of the heart; and calculating this in the manner described under the chapter Hydrostatics, the pressure must be about four pounds per inch. The same experiment applied to the veins would result in a column only half a foot in height, and hence the pressure would be about a quarter of a pound per square inch.

The force with which the left ventricle of the heart contracts is nearly double that exerted by the contraction of the right. This difference in the amount of force exerted by the contraction of the two ventricles results from the walls of the left ventricle being about twice as thick as those of the right; and the difference is adapted to the greater degree of resistance

which the left ventricle has to overcome, compared with that of the right; the former having to propel blood through every part of the body, the latter only through the lungs. Blood left in a vessel separates into two distinct parts; but this violent action in the heart keeps all mixed, and sends it forth in a condition to become the pendulum of life.

The aorta proceeds from the heart over the chest in an arched siphon-like manner, and then its scarlet contents are poured down, and the weight of the column of blood sends it through the capillaries to an equal height in a corresponding vein, as explained in Hydrostatics; fluids attain the same height in all communicating vessels. Not only does this law of gravity aid the circulation of the blood, but also the powers exerted to the extent of a column eight feet above the heart. When at the extremities the blood passes through narrow orifices, and is forced up the venous tubes by the same power which is sufficient to raise it above the heart, as if a force-pump were raising water in this manner and filling a tube, having power not only to this extent, but also to overcome friction, and sustain the column which is increased in weight in proportion to the depth.

When we draw in our breath the chest is expanded, and the muscular powers are then put on the stretch, circumstances rendering favourable the passage of the blood from the veins to the heart; and on expelling the air from the chest, the muscles contract and the diaphragm rises, by which the passage of the blood is resisted, and all return prevented by the valves in the veins; as the force is only equal to a column of half a foot, it is easily overcome.

An artery, or holder of air—as the ancients denominated it from finding it always empty upon dissection after death, and hence supposed it to be an air-tube—is circular in form, and consists of three strata of different substances called its coats. The inner is thin, strong, inelastic, and smooth; if injured, the regular round form is lost to the tube. The middle coat is composed of a number of muscular circular fibres. The outer coat is a condensed cellular substance and very elastic: thus there is an elastic power with a small muscular force; and if pressed, or much stretched, it easily returns to its former condition. When a small artery is cut across, it contracts at the part, and therefore aids the preservation of the life-giving

fluid; thus in bleeding to death the arteries contract in proportion to the decreased size of the stream. Sometimes, in dissection, a single fibre will contract as if it were a string tied round the mouth of the tube, and when tied by a thread the parts around contract, and firmly secure the orifice. The arteries contain about five pounds of blood, and their pulsation is felt over the whole body nearly at the same instant.

We have seen that the heart keeps up a tension or pressure in the arteries of about four pounds on the square inch of their surface; and with this force, therefore, is propelling the blood into the capillaries. If these last were passive tubes, constantly open, such force would be sufficient to press the blood through them with a certain uniform velocity; but they are vessels of great and varying activity; it is among them that the nutrition of the different textures of the body takes place, as of muscle, bone, membrane, &c.; and that all the secretions from the blood are performed, as of bile, gastric juice, or saliva, &c.: and to perform such varied and often fluctuating offices, they require to be able to control in all ways the motion of the blood passing through them. The capillaries of the cheek, under the influence of shame, dilate instantly and admit more blood, producing what is called a blush; under the influence of anger or fear, they suddenly empty themselves, and the countenance becomes pallid—tears or saliva gush in a moment, and in a moment are again dried up; if a person having inflammation in one hand be bled from corresponding veins in both arms at the same time, twice or thrice as much blood will flow from the diseased side as from the other. Similar changes occur in many other instances. Now the only mechanical action of vessels capable of causing these phenomena must occur in contractile or muscular coats; and with reference to such action, it merits notice that arterial branches have always more of the fibrous or contractile coat in proportion as they are smaller.

A muscular capillary tube strong enough to shut itself in spite of the action of the heart, is also strong enough to propel the blood to the heart again through the veins, even if the resistance on that side were as great as the force on the other. For if we suppose the first circular fibre of the tube to close itself completely, it would, of course, be exerting the same repellent force on both sides, or as regarded both the artery

H 2

and vein. If then the series of ring-fibres forming the tube were to contract in succession towards the vein, as the fibres of the intestinal canal contract in propelling the food, it is evident that all the blood in the capillary would thereby be pressed into the vein towards the heart. If, after this, the capillary relaxed on the side of the artery so as to admit more blood, and again contracted towards the vein as before, it might produce a forward motion of the blood in the vein, independently of the heart. We, of course, state this merely as a possibility, for the intimate nature of capillary action is not visible, and is not positively ascertained.

It is capillary action which absorbs and moves the fluids of the classes of animals which have no heart. It must also be the power which moves the blood in warm-blooded monsters formed without hearts. There are cases of apparent death among human beings where the heart remains inactive for days, and yet a degree of circulation sufficient to preserve life is carried on by the capillaries. In further illustration of capillary action, we have the absorption of nourishment from the alimentary canal by the lacteals; and perhaps, to a certain extent, the circulation of the blood in the liver of animals. In this last case, the blood collected by veins from the abdominal viscera, instead of going directly to the heart, is again distributed through the liver by the branches of the portal vein; and is then again collected by ordinary veins, and carried to the heart. It thus moves through two sets of capillaries in passing from the arteries to the heart again.

The action of the capillaries is the cause of that singular phenomenon which prevented the ancients from discovering the circulation of the blood, viz. the empty state of the arteries after death. All the muscular parts of an animal, including, therefore, the contractile coats of vessels, retain their life, or power of contracting, for a considerable time after respiration has ceased, as is seen in the recovery of persons apparently drowned or suffocated; in the leaping of a heart taken from an animal just killed; in the actions resembling life which can be produced, by the agency of galvanism, in a body recently dead; and still more aptly for our purpose, in the total disappearance of a local inflammation after the death of a patient. Inflammation involves a gorging or over-distension of the capillaries; and when the heart has ceased to press blood into them, the

contractile force remaining in them, even under disease, and in a dead animal, is sufficient to squeeze the blood out of them, and often to remove all trace of the malady which has been fatal. In ordinary cases, the capillaries throughout the body remain alive and active for a considerable time after breathing has ceased, and they work like innumerable little pumps, emptying the arteries into the veins. As the red blood is their proper sustenance as well as stimulus, they work as long as there is any of it coming from the arteries behind them; the capillaries of the lungs, however, soon cease to act, because, after breathing has ceased, they are filled with black blood, and are moreover compressed by the collapse of the chest, and all the blood accumulates behind them. The capillaries may continue to be filled from the arteries, either in consequence of their elasticity opening them with what is called a suction power, or of an absorbent power dependent on life, like that of the lacteals and of the absorbents all over the body, and, perhaps, of the vessels in the roots of vegetables. When death is produced by lightning, or by the poisons which destroy muscular irritability, and therefore capillary activity, the arteries after death are found to contain blood like the veins. In a living body, if an artery be tied, the part beyond the ligature is soon emptied into the veins, and becomes flat. The experiment has been made even upon the aorta itself.

The empty state of the arteries after death is still ascribed by some teachers to the momentum with which the blood is supposed to be thrown out from the heart in its last contraction, sufficient, according to them, to squirt it fairly through the most distant capillaries; a doctrine exemplifying the carelessness with which able men sometimes receive and repeat opinions, to which their attention has never been fully awakened. The effect supposed here would not follow, even if the dying action of the heart were the strongest possible; while, in reality, it is in most cases so feeble, that the pulse for some time ceases to be perceptible at the extremities, and the diminished circulation lets them become cold. Other physiologists teach that an artery is capable of contracting directly upon its contents, so as to expel even the last drop; but large arteries, when emptying, do not contract *roundly* like an intestine; they become *flat*, like elastic tubes of leather sucked empty, and no contractile action of the vessel itself could bring its

sides together in such a manner. If arteries emptied themselves by their own action, the pulmonary artery should be more certainly empty than the aorta, because it is shorter; yet it is always full, the chief reason being, as already stated, that the pulmonary capillaries cease to act after respiration has ceased, because the blood in them is the venous or dark blood, and therefore not stimulant.

Besides the downward flow of the blood, there is also the important upward one to the head. The head, being a close bony cavity, is not susceptible of atmospheric pressure, but the veins and arteries that spread over it are kept full from that cause, of which we have spoken in a previous page; and though the quantity may vary in other parts of the body, it does not do so in the head, where the vessels are in a similar position to that of a siphon in action. When the flow of blood to the brain is interrupted by the cessation of the action of the heart in fainting, or the supply of fresh air to the lungs cut off, so that the blood rises to the head impure, as in suffocation, insensibility takes place, and if not speedily relieved, convulsion and death. The arteries of the brain, not having to sustain the same outward pressure as in other parts of the body, are considerably weaker, while the veins are placed in grooves of the bone, and have a strong covering, so that they cannot collapse by any sudden tension of the arteries, as the veins would do in other parts of the body, and thus are singularly adapted for the preservation of thought and life.

There are other parts subservient to the functions of the body, which are equally surprising in their adaptation to the purposes for which they were designed, but they do not come within the province of this work.

Man has been compared to a machine, but we consider inaptly so; for no machine is at all comparable to that frame sent forth in creation, when God said, "Let us make man in our image, after our likeness," and He "created man."

Examine the head, the brain, where the union of spirit and body resides, and the mind emanates to guide the actions. Consider the organs of sense, the eye to see, the ear to hear, the nose to smell, the mouth to taste, and the skin to touch, while thus holding communion with the objects around. For safety, by communicating sensation to the brain, and the will to the muscles, do we see the beautiful arrangement of the

nerves. Then there is the mechanism of the muscles and tendons, giving the power of locomotion to flee from danger or supply wants. There is firmness, shape, protection, and strength to all the soft parts, from the bony skeleton throughout the entire body, having ligaments to bind them together and allow of motion, to the smooth slippery surfaces to prevent wear and afford easy movements. The hollows are filled up with fleshy or fatty matter, and the whole is made compact and defended from injury by the covering of the skin. That thoughts and feelings may be communicated, and the grand gift of social intercourse enjoyed, there are the organs for the faculty of speech. That this body may endure by being refreshed, renewed, and repaired, there is blood impelled by the heart and the arterial system, while the veins bring back that which is not required, and with it the collected refuse matter: this is separated by glands and other organs straining it, and the useless superfluous parts pass away by excretory organs. Man breathes, and thus his blood is purified, which supports the warmth of his body, and beyond its necessity for the continuance of life we know little. The teeth reduce the bulk of the food procured by the hands; and the stomach chemically changes it: by such means fresh blood is created. The stomach announces its wants, and tells when sufficiently supplied. Thus, then, these are properties that leave far behind any machine ever contrived by man of internal powers of self-preservation, that palpably proclaim in their formation the wisdom and wonders of a divine Creator.

To finish with a summary of the most striking characteristics of the human body, and which may awaken in some a spirit of inquiry, and in all a deep reverence for the divine power that could so wisely and with such love give to us such perfection of organization, we state a few facts about the human frame. The prop-work, or skeleton, consists of 261 bones, weighing about 14 lbs., and is one inch less in height in the dead than in the living man; these bones are moved by 436 muscles. The mean weight of an Englishman is 151 lbs., his height 5 feet 9 inches; the seat of mind, the brain, exceeds in weight twice that of any other animal; he tears and grinds the food that nourishes his body with 32 teeth covered by a substance nearly as hard as iron; he breathes 18 times a minute, and inhales in that time 18 pints of air, or

more than 57 hogsheads in a day; every twenty-four hours he consumes $10\frac{1}{2}$ cubic feet of oxygen; and gives forth, to feed vegetation, annually 124 lbs. of carbon; in infancy his blood pulsates 120 times per minute, in manhood 80, in age 60 times, and the weight of red fluid circulating in his veins is about 28 lbs.; his heart beats 75 times per minute, and drives at each beat 10 lbs. of blood on its journey throughout the body; thus in twenty-four hours 12,000 lbs., or more than 24 hogsheads, pass through the heart, and 1000 ounces of this very hour visit the kidneys. In our breathing apparatus, the lungs, are 174,000,000 holes, or cells, that would cover a surface 30 times greater than the body; 7,000,000 pores carry off the used portion of the human body, each of which is about a quarter of an inch in length; and thus there is a drainage of nearly 28 miles by means of small tubes, and 33 ounces of insensible perspiration escape in 24 hours—a fact sufficient to impress the mind with the importance of ablutions; the weight of atmosphere which presses upon every ordinary-sized person is about 13 tons.

Fig. 65.

CHAPTER IV.

HYDROSTATICS.

This word is a Greek compound, signifying *the laws of fluids at rest.* The branch of science to which it refers treats of the

weight, pressure, and equal balance of fluids in a state of rest.

Matter has three peculiar forms: solid, as the earth; liquid, as the ocean; and aëriform, as the atmosphere we breathe.

Fluids are said to be elastic and non-elastic; by which it is meant, that some cannot be compressed into a smaller bulk, as water, oil, mercury, and alcohol; while others are compressible into a smaller space, as air, steam, and gas. This is not strictly correct, for those which were at one time thought to be incompressible are now discovered to be slightly so.

Neither the form nor size of the atoms comprising water are known, but they must be very minute, as they penetrate the substance of most bodies, pass up the small tubes of fibrous materials, and float in the atmosphere as mist and clouds. They are generally supposed to be globular.

It does not then appear that fluidity arises from the shape of the particles of water, but from *the imperfect cohesion of the atoms.* Some fluids have more tenacity than others, as tar, honey, oil, which are viscous and imperfect fluids in comparison with water, mercury, and distilled spirits.

Solids have a centre of gravity, and, bound by attraction in a body, fall with great force. If the air were withdrawn, a mass of water would fall with the like effect; but fluids have less attraction among their atoms, and it is their easy separation which causes them, when in small quantities, by the resistance of the atmosphere in falling from a height, to form into small drops or globes, with all the lightness with which a solid piece of timber reduced to sawdust would fall if poured from an elevated place.

Level Surface of Fluids.

Every atom of fluid being attracted to the centre of the earth, and having an independent gravity, its surface becomes a perfect level to the face of the earth.

But as the earth is not a true level from being a sphere, neither is water; as may be seen when watching a vessel sailing from a shore; the hull disappears first, then the lower parts of the mast, and gradually the entire is lost to view; when first seen approaching the land, the pennant comes into view, then the cross-trees, the deck, and the hull. Nevertheless, what is understood by a dead level, means that every particle is at an equal distance from the earth's centre.

Were a true, or apparent level, as it is termed, taken on the earth's surface, it would be found that at every mile it was 7 inches and 9-10ths higher than a natural or dead level; this demonstrates that the bend of the earth is nearly eight inches a mile.

When railway engineers proceed to set out their lines, they have attached to their instruments a small glass tube, called a level, filled with spirit, except one bubble of air, and when the air is an equal distance from both ends, their theodolite is level: then they look through a telescope, or sight-hole, at a pole having figures or lines upon it, which has been placed at a measured distance—say of a mile; the figure which the sight-hole cuts across is then noted, and for the convexity of the earth 7 inches and 9-10ths are allowed off, which gives the dead level. In forming a canal, were the same rule not observed, and a true level used instead of a dead one, the water would all rest at one end, for in three miles it would have to ascend from the surface of the earth nearly two feet. A fall of three inches per mile gives a motion to a stream or river of about three miles per hour.

A B (fig. 66) is a spirit-level, C the small space filled with air: to this instrument, for surveying purposes, two "sights," or eyepieces, are usually attached. When the bubble stands in the middle of the tube, any object covered by the cross-wires in the sights is on the same level as the instrument. There is often a limb, A F, attached, having sights also, and moving round A on a quarter of a circle (*a quadrant*) divided into ninety equal parts. If it is desired to know how many degrees any object is below the level of A B, A F is turned until the cross-wires in the sights of this limb cover it, and the number of degrees between the edge of the limb F and the level E observed. If the object is above the level, the instrument is turned up; that is, the arm A D is brought up to it, and the observation made in the same manner.

Fig. 66.

Water seeking its level is the cause of many of the changes that occur on the surface of the earth; as seen where running streams carry forward a deposit to the ocean, ultimately form-

ing new and extensive lands for the habitation of man. Water seeking its level grinds down rocks, washes away mountains, leaves bare or fills up lakes, and tends to make the surface of the earth a smooth plain, luxuriant and not perniciously humid for the family of man.

If we now connect together a series of vessels, no matter what may be their shapes, or how extensive the system, so that water may rise from the main channel, A B (fig. 67), into them, we shall find, upon pouring water into one, that it will rise to the same level in all the vessels. In open channels liquids cannot be made to stand at a higher level at one end than at another—they always adjust themselves to a horizontal level; this is observable in canals. In the great aqueducts of the ancients, the water, of necessity, was always flowing downwards, and thus they were inferior in utility, for watering cities, to the system of closed pipes which we now adopt.

Fig. 67.

The reservoir for a modern town is placed upon a distant hill, or water is raised by engine-power to a high level in "stand pipes;" an elevation is thus obtained superior to that


Fig. 68.

of any of the houses which are to be supplied with water;—from this reservoir A (fig. 68) the water flows through a series of pipes, perhaps for many miles, yet at the remotest extremity, B, the liquid will rise to the level of the reservoir, A E. By judicious arrangements, the water might, without the aid of

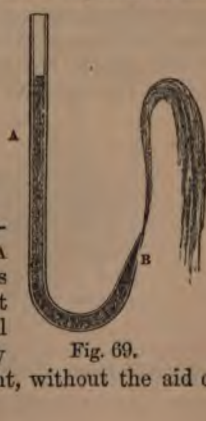


Fig. 69.

engines, be thrown over the highest buildings, in case of fire, in almost unlimited quantities, since the pressure of the column A (fig. 69), the height of the reservoir, would force the water from an opening at B, to nearly the same height as that column.

Upon this principle ornamental fountains are constructed, and a pretty illustration may be formed in the following manner:—Bend a glass tube, *a b* (a *siphon*), as shown in fig. 70, and immerse one end in a vessel of water, *c*; exhaust the air from the tube by applying the mouth to the orifice at *a*, and a jet will thus be produced proportional to the height of the column. The great fountain at Chatsworth, which throws a column of water three inches in diameter 285 feet high, is supplied from a reservoir on a neighbouring hill, at an elevation of nearly 400 feet, an the supply-pipes are fifteen inches in diameter. A jet 100 feet high is found, experimentally, to require the pressure of a column of water 133 feet high.

Fig. 70.

An artesian well is formed on this principle. A peculiar stratum, let us suppose it to be chalk, sand, or any porous matter, rests upon a bed of clay, or upon rocks which will not admit of the escape of the water accumulated from the deposit of atmospheric moisture, in the form of rain or dew, along the hills. This stratum of chalk or sand is also covered with a

Fig. 71.

tenacious mass of clay—as the London clay, or some equally

impervious body. Under these conditions it will be evident that the stratum *a a* (fig. 71) becomes a reservoir of a greater or less extent, and if, by boring through the superincumbent mass, we form an opening into this stratum, as at *b*, the water will rise in it, and flow over in a jet proportional to the height of the water in the stratum from which it flows.

The Pressure of Fluids is equal in all directions.

Solids, from attraction, are pressed downwards toward the centre of the earth, and water obeys the same universal law.

But there exists this difference and peculiarity in fluids as compared to solids, that a body of water or other fluid, being acted upon by a force in any one direction, presses upwards, sideways, and in every direction, with the same force.

If a bladder be filled with air or water, and tied at the neck, then pressed upon, not only will the parts underneath the weight be compressed, but every other part of the bladder equally, all offering a reaction or resistance to the weight. This may be proved by making a small puncture at the furthest point from the pressure, when the air or water will issue out with force.

The upward pressure of water may be seen on plunging the hand into a jar of water, when the water will press it upwards; or in attempting to put a cork into a bottle which is filled to the brim with liquid.

That it presses equally may be proved by a simple experiment. Let A (fig. 72) be a close vessel filled with water, having two tubes, B and C. Say that B will admit a cork measuring one inch in area, into which a stick is fixed as a piston, and C admits a bung measuring ten inches in area. By pressing upon the piston at B with the weight of one pound, the bung at C is pushed up

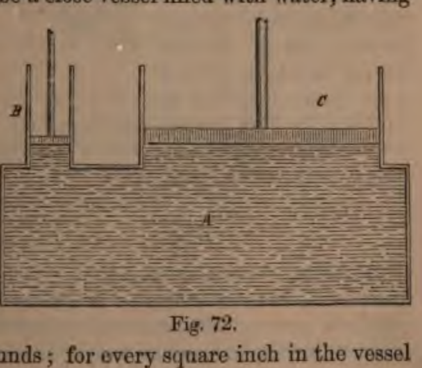


Fig. 72.

with a force of ten pounds; for every square inch in the vessel

is acted upon with a force of one pound. Thus, a small quantity of water confined in a space having a slight pressure on its surface may act as a mechanical power with a force equal to hundreds of pounds. If the tube B hold a pound of water, and it be poured in, the cork having been withdrawn, the same results will take place as when a pound of pressure is applied to the cork. But for the bung to rise one inch, the cork must descend ten inches.

Again, suppose only one tube, measuring ten inches, a 100 lb. weight applied, and a hole made in the side or bottom of the vessel of the same size as the tube, the water would rush out if not kept in by a force equal to 100 lb. This shows that the pressure at the bottom or sides is equal to that at the surface; in short, the same in all directions.

Pressure made on a small surface is multiplied when transmitted to a larger one.

The best illustration of this is thus given:—A B C D (fig. 73) is a cylinder, in which, moving freely, but water-tight, is a disc, F G, attached by a rod to one end of a beam: a tube H is closely fitted into the cylinder. A measured quantity, say a pint, of water is now poured into the cylinder, which is then balanced by weights in the scale L. If now the rod is raised, to force some water into the narrow tube, the water will appear to weigh more than it did; additional weights must be added to restore the equilibrium; and if twelve inches of water are forced thus into a small tube, three pounds will be added to the apparent weight of the same volume of water.

Fig. 73.

Perpendicular Pressure.

In solids, the lower atoms of matter support those placed upon them, as the foundation of a house bears the whole of the lofty pile above. The same rule extends to fluids, every layer of atoms having to bear the weight of those resting upon them.

The weight of solids is estimated according to their size or quantity, but the pressure of fluids is as to their perpendicular height; hence, to estimate the pressure, the area of the base is multiplied by the perpendicular height and the density of the particular fluid. Thus, then, if water be in a vessel that slopes from the bottom to the rim, the pressure will gradually decrease as it approaches the top, for every upward line of atoms acts as a separate column sustaining its own weight.

If a tube, one inch square in the inside, and two feet long, having a flap at the bottom, attached at one side by a hinge, and at the opposite having a cord passing over a pulley, with a weight hung from it, be filled with water, it will be found that this column, two feet high and one inch square, acts with a force of nearly one pound; so that we may generally say at any depth, every two feet of water presses on the side or bottom of a vessel with a weight of one pound on every square inch (fig. 74).

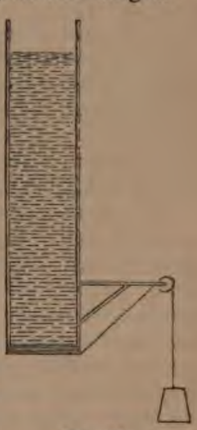


Fig. 74.

The effect of the increase of pressure as to depth is exemplified in the wrecks of vessels near the coast where the water is shallow; there they float to the surface, and are cast on the shore; whereas in such a case as that of the unfortunate 'President,' which went down in deep water, the pressure was probably so great that the water filled the pores of the wood, and became so heavy that not an atom of the wreck floated to the surface to point out the spot, or serve as a memento of its fate.

If we watch a bubble of air or steam rise from the bottom, we shall perceive it start on its upward journey as a little silvery bubble; but as the pressure becomes less, the size increases, until it bursts or rests at the surface.

At a depth of ten fathoms, a strong, square, empty glass vessel is crushed to pieces.

A living man can only descend to a certain depth, as the pressure of deep water upon the elastic air contained in the chest is such as would speedily cause death.

As fish are only found near to coasts and in shallows of t

ocean, it is supposed that a light atmosphere of water is more suitable to them than the density of the deep valleys of their natural element.

Lateral Pressure.

Fluids act in all directions, pressing downwards, upwards, and sideways. The force that water exerts on a square inch of surface one foot deep is seen to be $\frac{1}{2}$lb., on two feet 1lb., on three feet $1\frac{1}{2}$ lb., on four feet 2 lb., on five feet $2\frac{1}{2}$ lb., on six feet 3 lb., and so on.

But in lateral pressure there is this to be taken into account, that as it presses against the upright sides less at the top than at the bottom, to find the amount of pressure we must balance the account, and the true force against the whole side will be found to be that which acts on the middle part, half-way from the top and bottom, when the sides are perpendicular.

Now, if we take an open square vessel full of water, say twelve feet deep, the pressure on the bottom will be 6 lbs. per square inch, equal to 864 lbs. on a square foot, and the pressure on the side half-way down, that is six feet from the top and bottom, exactly one-half, or 3 lbs. on a square inch; because the six feet is just one-half the depth of the water at the bottom, and what is wanting above the six feet in pressure is made up by the greater stress below, hence an average pressure on the whole side results. The lateral pressure then is 432 lbs. on each square foot of the side (fig. 75).

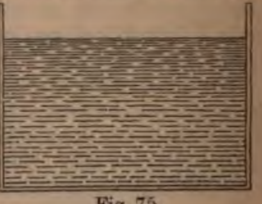


Fig. 75.

If it be wished (without reference to pressure on the bottom) to know the pressure on the sides of a vessel intended for holding water, the manner of doing so is first to find the area of the sides; suppose it to be 12 feet deep and 20 feet circumference, multiply 12 by $20=240$, then multiply this product by half the depth $240 \times 6 = 1440$; this gives the number of cubic feet of water, the weight of which presses against the sides; then, as before stated, a foot of water weighing 1000 ounces, the amount of pressure is $1440 \times 1000 = 1{,}440{,}000$ ounces, or 6000 ounces on a foot.

The extent of the breadth or length of the water makes no

difference in the pressure, whether it be a foot or miles; all depends on the extent of the side acted upon, and the depth of the fluid.

It is this law of nature that enables man to erect gates and banks by which he can shut out the ocean, as is done in many maritime ports, and in Holland; to keep out the whole body of a river by a coffer-dam, while he sinks a foundation and builds the buttress of a bridge; and to carry canals over mountains by means of gates: for an erection requires no more strength from having a sea pressing against it, than if it were a small quantity of water of the same depth; of course in saying this we do not take into account the force of the sea when agitated and driven with impetuosity against the erections intended to resist its encroachments.

It was the knowledge of the laws of pressure of fluids that caused the idea to be entertained of forming a ship-canal across the isthmus which joins North and South America, and of stemming out at one side the North Pacific, and on the other the North Atlantic Ocean, with as much ease as in forming dock-gates at Sunderland or Southampton.

As the pressure of fluids depends on the depth, it shows the necessity of having embankments broader at the bottom than the top, the hoops of vats closer and stronger near the base, and canals no deeper than necessary to float the vessels that have to be the means of the transit of goods or passengers.

In the adjoining figure A B (fig. 76) is supposed to represent a tall vessel full of water and kept so; from the centre is drawn a semicircle: three perpendicular lines, *d* 3, *c* 1, *a* 5, are also drawn, the lower and uppermost being at equal distances from the centre one. When the plug is taken out of the centre spout, the water flies as far as M, and the distance N M is double *d* 3; but from the spouts *c* and *a* the water only reaches to K, and N K is double *c* 1 or *a* 5.

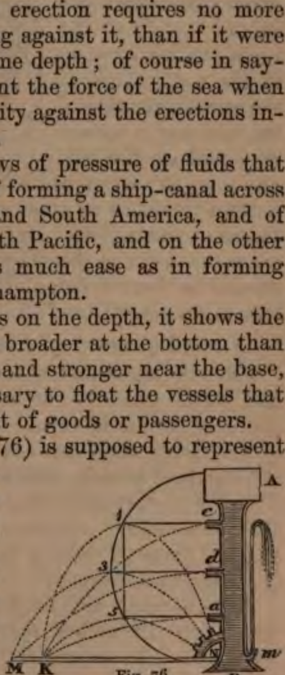


Fig. 76.

Thus then the rule is learned, that the horizontal distance to which a fluid will spout from a horizontal pipe in any part of the side of an upright vessel below the surface of the fluid is equal to twice the length of a perpendicular to the side

the vessel, drawn from the mouth of the pipe to a semicircle described on the altitude of the vessel.

Pressure of Water on the Base of its containing Vessel is in proportion to its Height and Base.

If a vessel in the form of the diagram be filled with water, the bottom does not sustain pressure equal to the weight of all the water it contains, but only as if there were a column of water, the same size as the bottom of the vessel, which rose up to the top. Now, if the vessel were turned up, and had a bottom as broad as the top, and a top as narrow as its base, then the pressure on the broad bottom would be as great as if the vessel were as wide at the top as at the bottom. In this case, the upright column which we pointed out in the other form of the vessel presses sideways as well as downwards, and thus an equality of pressure on the base takes place (fig. 77).

Fig. 77.

A small quantity of Fluid may balance a large quantity.

From the above fact, that the small quantity of a pound of water is capable of producing a pressure of thousands of pounds, arises what is commonly called the *hydrostatic paradox*, another form of which is the *hydrostatic bellows.*

Suppose two boards, each measuring 18 inches one way and 16 inches the other, to be joined together by leather or gutta percha, perfectly water-tight, in the same manner as a pair of common bellows; then a pipe 3 feet long be added, communicating with the

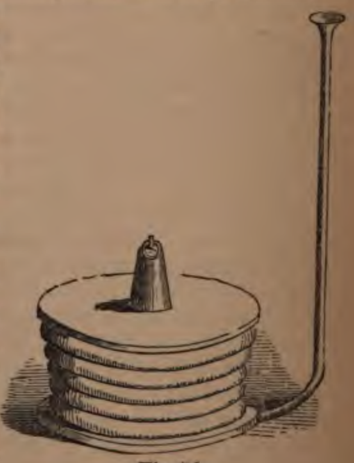


Fig. 78.

bellows, which pipe, when full, will hold about a quarter of a pound of water. On the top of the upper board place a 300lb. weight, and pour water into the small pipe, it will run in between the boards and raise the weight; by continuing to pour in water, the boards will be raised to the extent that the leather or gutta percha will permit them to separate, and the little stream of water that remains in the pipe, weighing a quarter of a pound, will about balance the 300 lb. weight, the water not being forced by the great pressure out of the pipe. A person may stand on the bellows and blow into the pipe, when he will raise himself up, and, by placing his finger on the top of the hole, sustain himself thus elevated with perfect ease (fig. 78).

Experiments have been tried on strong casks, having a tin tube twenty feet long fixed to them, water being poured in until they were filled, and it rose to within a foot of the top of the tube, when the casks burst with immense force. By increasing the length of a tube, and filling it with water, a pressure may be created to almost any extent. We may simplify the theory of such results by pursuing the subject a little further. If a pipe, exactly the same size as that used to pour in the water, were inserted in another part of the bellows or cask, the water would rise in it to exactly the same height as it stands in the supplying pipe: if a dozen or more tubes were inserted, the same thing would occur in every one of them. If a hole were made the same size as the bore of the pipe, holding the quarter of a pound of water, and the finger were placed upon it, a pressure equal to that of a column of water the same height as that in the tube would be felt; and if fifty or more holes were made, every one would offer this amount of resistance. Thus, on every portion of the inner surface of the cask or bellows of the size of the bore of the supplying pipe, there exists a pressure equal to the weight of the water it contains; and by multiplying the number of times that the size of the bore covers the surface by the weight of the water in the tube, the amount of pressure is ascertained.

In the bellows, which we cited as an example, one quarter of a pound of water in the pipe sustained 300 lb., or 1200 quarters of a pound; the area of the top of the bellows must therefore be 1200 times that of the pipe conveying the water. As the bore of the pipe is diminished, and its length increased,

so is the power of raising a weight multiplied. Now suppose the bellows were filled with water, and then a pipe screwed on 3 feet high, the water would only stand in the pipe to the same height as that in the bellows; place weights upon the bellows, and the water would rise up in the pipe, and, as just mentioned, the weight would have to be 300 lb. before the water would reach the top; lengthen the tube, and the weight would have to be increased. As it is known that 1000 ounces of water (or $62\frac{1}{2}$ lb.) measure a cubic foot, the weight of water can be ascertained in pounds.

The *hydrostatic press*, invented by Mr. Bramah, is one of the most useful and powerful applications of this principle. It is used by printers and paper-makers to give smoothness to the paper, and by dealers in light goods to compress their articles into a small space for transit; also as a machine for raising weights.

d (fig. 79) is a small forcing-pump, in a small tank, to drive the water into *g*, which is a stout cylinder. A closely-fitting piston in the centre moves freely upwards and downwards, but allows no water to escape; on forcing the water into *f*, the piston is driven upwards. *b* is the handle or lever by which the pump is worked; and *a* the pillars for supporting the entablature, and enabling it to resist the upward pressure of the piston. When the desired amount of pressure is given, a stop-cock *e* is

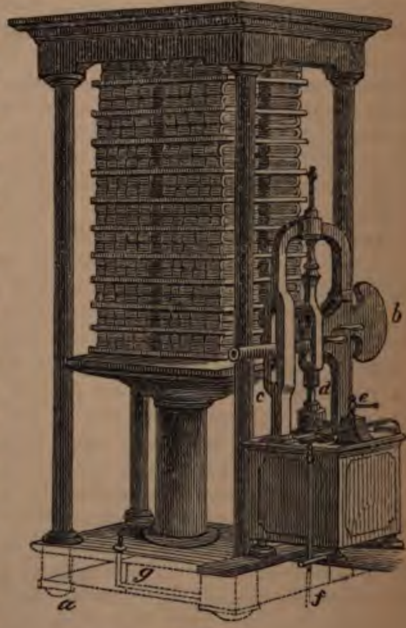


Fig. 79.

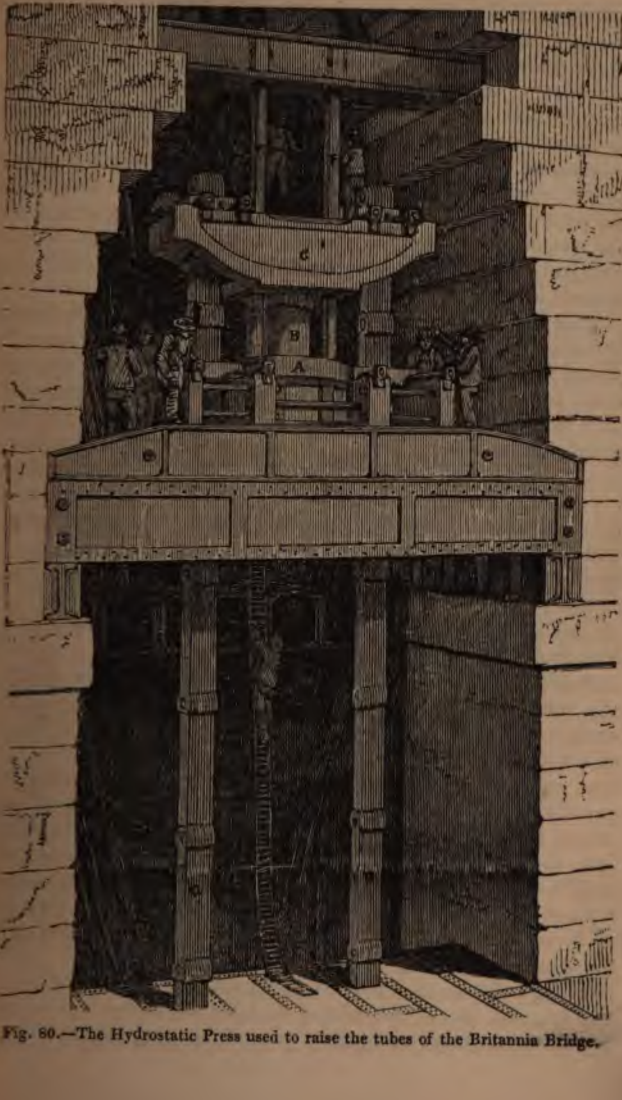


Fig. 80.—The Hydrostatic Press used to raise the tubes of the Britannia Bridge.

turned, and the piston remains at rest. As soon as the articles are supposed to be sufficiently pressed, the stop-cock is turned back, and, the water flowing out, the piston gradually descends. In this machine the pressure that is available is that on the bottom of the piston, and the force employed is the pressure on the water at the bottom of the piston in the pump; the power employed will therefore be to the effect produced as the area of the base of the small piston in *d* to the area of the piston *g*. When the bore of the pump is very small, and the power great, the force may amount to hundreds of tons. The pump in this case acts instead of a long tube, containing a small column of water.

Two of these machines were employed by Mr. Stephenson to raise the immense tubes of the Britannia Bridge from the Menai Straits to their proper elevation. Those used were the most powerful ever constructed, weighing forty tons each. The sides of the cylinder were eleven inches thick, and its weight was sixteen tons. The piston was twenty inches in diameter, and the pressure upwards of eight thousand pounds per inch! One press was perfectly competent to raise the tube (1800 tons), although two were used. The pipe, through which the water was forced into the cylinder, by means of a steam-engine, instead of the power of a man pumping, was made of cast iron, and only a trifle more than an inch in diameter, and its bore about half an inch (fig. 81). During the operation one of the pumps burst, upon which the skilful engineer made the bottom of the cylinder of a more rounded shape than it had on its first construction; by so doing, the pump proved capable of sustaining the immense pressure to which it had to be subjected. Such was the force with which the water was driven into the cylinder, that it was calculated to move a jet to a height of nearly 20,000 feet, which is more than five times as high as the top of Snowdon, 5000 feet higher than the summit of Mont Blanc, and nearly fifty times higher than the top of St. Paul's in London.

Fig 81.

If two pieces of wood be made so that their surfaces fit closely, and one of the pieces be fastened to the bottom of a vessel, then water be gently poured upon them, the upper

loose piece will remain at the bottom, because the water presses down upon it but not below; but if it be in the least raised, so as to allow the water to insinuate itself between, then it rises to the surface, because there is an equality of pressure, and the wood being lighter than the water, it at once floats.

The immense power of a small stream of water is one of those means which nature uses to rend mountains, be they of yielding earth or stubborn granite; a small quantity insinuated into a crevice brings down the towering cliff of hardened rock in fragments to the valley beneath. Thus, if a cavity *b* (fig. 82) in the face of the hill *a a* has no outlet, but is supplied with water through the fissures *c c*, the face of the hill towards *d* will be forced outwards, on the cavity *b* filling, with a power proportioned to the height of the fissures *c c* and the interior surface of the cavity *b*.

Fig. 82.

If a strong wall of masonry *b b* (fig. 83) be erected to hold up a butting in the earth *c c*, and proper holes *d d* be not left to drain off the water that may accumulate behind, the wall will be cast down, unless built with a strength calculated on the same principle as for a construction having to sustain a great weight of water; in fact, as an engineer would estimate a dock-gate.

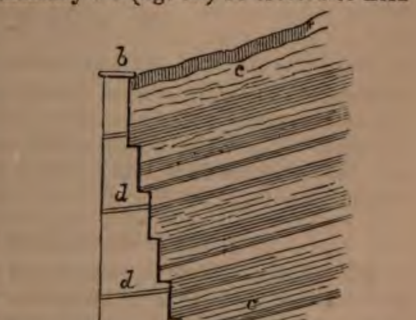


Fig. 83.

In many parts of London, during an extra high tide or much rain, drains will burst, and throw up the pavement as if a slight earthquake had rent them, which arises from the drains becoming choked, and the pressure of the water heaving up the superincumbent mass.

Equal Pressure.

As air presses equally on all parts of the human body and other substances, so does water on any substance immersed in it; thus, if a piece of cork be sunk a great depth, it will retain its former shape though its size be decreased; this is from the equality of pressure on all its parts; or if a piece of soft wax be inserted in a bladder of water, and a great weight placed upon it, the wax will not be changed in form, from the pressure of the water being equal on all sides.

The pressure of water laterally and downward has been exemplified, and the pressure upwards is seen by its rising in any hollow tube placed in water.

When a vessel is deep in the water and unfortunately springs a leak, from upward pressure the water rushes in with all the force of a column of water the size of the hole and the height to the water-mark. As the vessel becomes fuller and settles down nearer to the height of the water outside, the force of flowing in weakens, and ends with the last feeble drop that consigns it to the depths of the ocean.

CHAPTER V.

HYDRAULICS.

THIS name is from two Greek words, and strictly signifies the art of conveying water through pipes; it has, however, in science a wider range, teaching how to estimate the swiftness and force of fluids in motion, whether produced by natural or artificial means.

Of Fluids issuing from Orifices.

The velocity with which water spouts out at a hole in the side or bottom of a vessel, is as the square root of the depth or distance of the hole below the surface of the water. But this rule is not quite correct in practice, owing to the resistance offered by counter currents and friction.

In the last chapter we pointed out the pressure of water against the sides of any vessel that confined it, and stated that such pressure increased on the sides as the square of the depth of the water.

If two pieces of the same sized pipe be fixed in a vessel full

of water, and one be placed four times as far from the surface of the water as the other, the lower one will deliver just twice as much water as the upper one, at nine times the depth a triple quantity, and so on; as the distance is increased from the surface, so is the quantity of water discharged increased.

There is a close agreement between the law which regulates the motion of a fluid issuing from an orifice, and that which governs the descent of solid bodies falling through space. *The velocity with which every particle of a fluid issuing from an orifice, whether sideways, upwards, or downwards, arrives at the surface of the earth, is equal to that which it would have acquired by falling perpendicularly from the level of the fluid to that of the orifice.* Which is the same as to say, it is as the square root of the altitude. The fluid in issuing likewise obeys the general law of the motion of projectiles, and describes a parabolic curve.

The pressure on the bottom of a vessel, if the sides be perpendicular, is equal to the weight of the fluid; and as the pressure on any one side is equal to half the pressure on the bottom, when the sides and bottom are equal, the pressure on the four sides and bottom of a square vessel is equal to three times the weight of the fluid. Thus, if the water weighs 12 lb., the pressure on each side of the vessel will be 6 lb. which multiplied by the four sides is equal to 24 lb., add to which the weight on the bottom 12 lb., the total is 36 lb. pressure, three times the weight of the fluid.

The pressure against the side of a vessel increases in proportion to the square of the depth; but in water spouting from a pipe, the velocity increases as the square root of the depth; and if in a brewer's vat constantly kept full there were a pipe a foot below the surface, and it was desired to draw off the liquor from it three times quicker, another pipe would have to be placed 10 feet from the top, and if four times faster, 17 feet from the top, as before named.

The friction of water in pipes is found to be considerable, therefore the smoothest material is always chosen for their manufacture; and whenever practicable, when large supplies of water are needed, to reduce the friction, the pipes are made enormous in size. The friction in an inch-pipe about 67 yards long is found to have such effect, that only one-fourth of the water will be discharged that would pass direct from a hole of

the same bore made in a thin vessel. The most advantageous application for the discharge of water is that of a short pipe, in length only twice its width or diameter.

If a pipe be protruded into the interior of a vessel, that is, not flush with the sides, the discharge of water is diminished. To ensure a free egress of water it is necessary to commence the pipe in a funnel-shape, as then the particles of the water do not so readily cross and impede each other.

Thus, in the figures annexed, where the vessel marked *a* (fig. 84) is being emptied of its contained water, currents cross each other as indicated by the arrows, and much impede the rapid flow of the water; but in the figure marked *b*, having a funnel-shaped mouth, the water flows easily and rapidly, the sloping sides of the exit-pipe facilitating the flow.

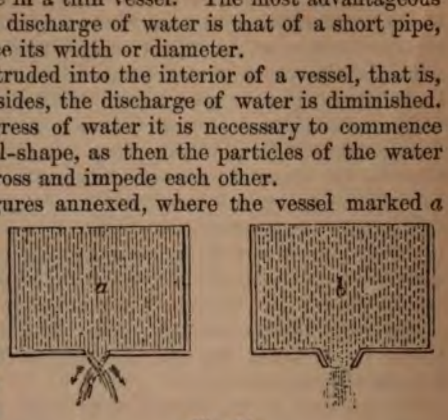


Fig. 84.

It must be self-evident on the slightest reflection, that the velocity of water running out of a vessel which receives no additional supply will continually decrease, in proportion as the quantity lessens, from the surface becoming lower and the depth less. If a vessel were divided into 36 spaces, and would empty itself in 6 minutes, the water would descend through 11 of the spaces in the first minute, 9 in the second, 7 in the third, 5 in the fourth, 3 in the fifth, and 1 space in the sixth and last minute. If the vessel were kept full, it would discharge as much water in half the time.

The flow of water through orifices under certain and uniform circumstances is so steady, that prior to the invention of clocks advantage was taken of it to regulate and indicate the divisions of time. The contrivances thus used were called *clepsydræ* by the ancients. The most simple arrangement was where water flowed out of a vessel properly graduated. But as we have just shown that the rate of flow would not be uniform, but faster when the vessel was full, it became necessary to adopt some contrivance to compensate for this irregularity. The most commonly used arrangement for this purpose

was either to employ a vessel smaller at the bottom end, and this divided into a certain number of equal parts, or to use a vessel of the same diameter throughout, the height being divided into a number of unequal parts, the least division being nearest the bottom. These plans were difficult to manage. We here give a drawing of a most ingenious plan, by which the water-clock is self-regulating, the design of Mr. Partington; by this contrivance equal quantities of water are discharged in equal spaces of time. It will be perceived that the siphon (see PNEUMATICS) plays an important part in the apparatus; it forms a good example of the adaptation of purely philosophical principles to practical purposes. The cylindrical tube *a a* (fig. 85) holds the water, which serves as the measuring medium. A cork float *c* moves up and down in *a a* like a piston; the leg of a siphon *b b* passes through this float, and is suspended by a slight cord over the pulley *d*, supported by the standard *e e*; the weight of the float or siphon is nearly counterbalanced by the weight *f*. A pointer *b* is fixed near the delivering end of the siphon; this marks out the divisions of time placed at the side of the instrument. It is obvious that as the float by which the siphon is supported is always immersed to the same depth in the water, the outer leg will always remain in the same relative position to the surface of the water in the tube; thus the pressure being always the same, the flow of water will be uniform. As the water flows out of the cylinder by the siphon, the float and siphon fall, and the pointer consequently

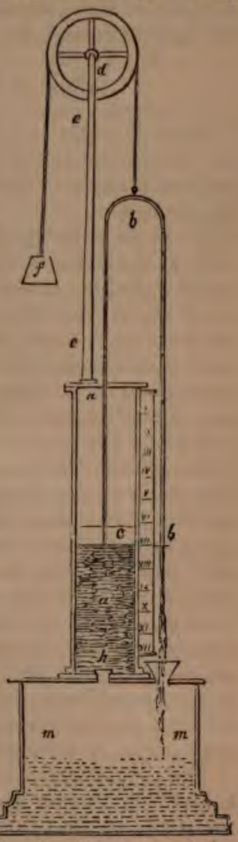


Fig. 85.—The Water-clock.

indicates the hour. The water discharged from the siphon falls into the box *m m*; and when required to be replaced in the tube the instrument is inverted, the water flowing into the cylinder through the valve *h*, which opens inwards, allowing the ingress of water, but preventing it from leaving the cylinder.

Flow of Water in Open Channels.

Water in rivers and canals, the bed of which inclines, flows on in obedience to the law of gravitation. But its velocity is materially lessened by friction against the bottom and sides of the channel.

Were the velocity of rivers not checked by friction, their force would be frightful. The Rhone, from 900 feet above the level of the sea, would pour into the ocean at its mouth with a velocity of 240 feet a second, or 164 miles an hour; and the Thames, with a fall of 100 feet, 54½ miles an hour. The friction increases as the stream proceeds, until the flow becomes limited and easy. But this depends on the quantity of descent in a given distance, and the proportion of the surface of the bottom to the quantity of water. The torrents that rush down some of the Alpine steeps at the rate of eight miles an hour will carry with them stones four feet in diameter; when the rate is two miles an hour, the size of the rolling stones is about three inches in diameter; and when reduced to a quarter of a mile an hour, small sand only is moved along. Thus rapid rivers are stony, slow ones sandy or muddy. A river is most rapid in the centre of the channel, less so at the bottom and sides from the increased friction. This is the reason why ships sailing with the tide go into the middle of the stream, and those sailing against it keep in shore. The mean velocity is found in half the square root of the extreme difference of the velocity in the channel and at the bottom.

The rate at which a river flows may be estimated by placing against the stream a funnel having a bent tube; the higher the water stands in the tube above the level of the river, the greater the velocity. Some persons mark with a watch the time taken by a floating body in passing; then by calculating the width and depth, making some allowance for friction, they ascertain the quantity of water and velocity of its passage.

The velocity of a stream or river varies according to cir-

cumstances. When the bottom has an inclination of about four inches per mile, the rate at which the water flows onward will be found to be nearly three miles an hour. A long straight river will be always found a rapid one; and many who have studied the subject can form a pretty near estimate of the rate of the current by merely glancing at a map where its course is laid down.

It is curious, at the mouth of a river flowing into the ocean, to observe the meeting waters passing in different directions; thus the heavy sea-water will be flowing in while the light fresh water is heaved to the top and continues flowing out, so that there appears for miles out to sea a smooth muddy snake-like current spread over the vigorous heaving bosom of old Father Ocean.

Two streams which meet when flowing in the same direction, are a still longer time in mingling their waters. They will run side by side for a considerable distance, each carried on separately by its own impetus. The greater the velocity of the currents, the longer will they be without intermixing. This curious phenomenon is well seen where a muddy river meets a clear one, as in the confluence of the Arve and the Rhone near Geneva, and of the Rhine and Main at Mayence.

Motion of Ships Sailing.

If a ship be sailing at the rate of one mile an hour, it displaces so many particles of water; if it sail two miles an hour, it must displace twice as many particles, to do which will require twice the force to accomplish: but in doing this, not only is twice the force required to attain the speed, but to displace the water with twice the velocity, the power has to be again doubled; thus, then, four times the force is required; therefore it is as the square of the velocity of the moving body. In trebling the speed a force of nine will be necessary; and four times the speed will be obtained if a force of sixteen be applied to overcome the resistance. Then in steam navigation, if a 20-horse engine propels a vessel seven miles an hour, a 40-horse power will be required to impel it ten miles an hour, and so on, which causes very swift steamers to occupy a vast amount of space in carrying coal for their engines.

From calculating this resistance, it is found that sailing

vessels can hardly attain a greater speed than fifteen miles an hour.

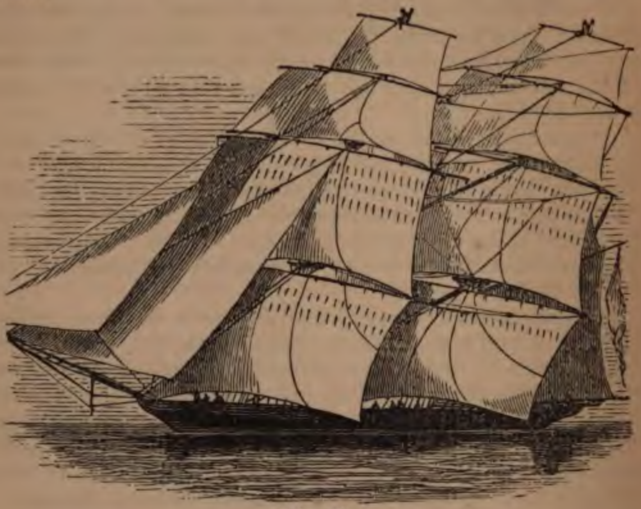


Fig. 86.

"This law," says Dr. Arnott, "explains also why a ship glides through the water one or two miles an hour when there is very little wind, although with a strong breeze she would only sail at the rate of eight or ten miles. The hundredth part of that force of wind which drives her ten miles an hour will drive her one mile an hour; and the four-hundredth part will drive her half a mile. Thus, then, during a calm, a few men pulling in a boat can move a large ship at a sensible rate."

The action and reaction of a solid and a fluid is felt when a ship is anchored in a stream, the strain upon it being as the square of the velocity of the current. If the strain on a vessel in a stream having a speed of four miles an hour be equal to 16 cwt., then if the stream be eight miles an hour the strain will be 64 cwt. The law is the same as for a solid moving in a fluid.

Of Fluids which meet oblique Surfaces.

If a solid and a fluid meet obliquely, the effect on the sur-

face of the solid is always perpendicular, but the impulse received by the force is less in proportion to the obliquity. This is explained by the *resolution of forces*. The force of the fluid is resolved into two others, one parallel to the side of the body impinged upon, the other perpendicular to it. The latter only is effective. The vanes of a windmill directly face the wind, but the blades of the vanes are placed obliquely from the thick arm, gradually inclined from the plane of their rotation as they approach the axis; therefore the action of the wind being perpendicular to these parts of the surfaces, the arms are driven onward, and, turning round, the axle communicates motion to the machinery. In some windmills, instead of covering the vanes with canvas, thin wood has been successfully employed. The Chinese often have wooden sails to their vessels, and the recent triumph of an American yacht with a straight stiff sail has demonstrated the advantage of this mode of rigging. The subject is now engaging the attention of nautical men, and we should not be surprised if some day wooden sails were adopted. They afford considerable facility in their management compared to the sails now prevalent. If they were made similar to a Venetian-blind, they could with ease be furled on deck, and all the effects of reefing be accomplished by turning them edgeways to the wind.

It is on *the resistance of a fluid to the oblique surface of a moving solid* that depends the power of that great discovery in modern navigation—the Screw Propeller. In 1802, Mr. Shorter applied a propeller like the sails of a windmill to the stern of a vessel in the Thames. Various attempts were afterwards made in this mode of propulsion, and in 1836 Mr. Smith took out a patent and built a vessel for the working of which there was a screw of 2 feet diameter, having a pitch of 2 feet 5 inches. The next important vessel was the 'Archimedes,' built by the Rennies, the screw of which had two threads opposite to each other, 5 feet 9 inches in diameter and 8 feet pitch. From this time the subject engaged the attention of scientific men, and the angle of the blades of the screw was owned to be one of the most important points in the perfecting of this system of navigation. The numerous experiments that have taken place, seem now to have led to a decision in favour of the angle of the outer edges being $12\frac{1}{2}°$ with the plane of rotation—the angle of the vanes of a windmill.

We have often delighted in the exercise of sculling a boat, that is, by placing an oar out from the stern, and by giving the end in our hands a motion of a segment of a circle, driving the boat along; the surface of the oar that presses the water is turned obliquely backward, and the reaction of the water forces the boat onward. The tails of fish generally act in a similar manner, while the fins direct the motion.

Of Water as a Motive Power.

Water in motion, flowing from ceaseless springs, and teeming from extensive water-sheds, in its passage to the ocean seeks a course amid the valleys of the earth. The weight and momentum contained in this gift of nature, man, from time immemorial, has endeavoured to turn to his own advantage; and although the steam-engine has stepped in, and rendered this power less important than heretofore, yet where water-power is abundant and constant, it offers the desideratum of economy, for various purposes of industry. Thus the principles of hydraulics, combined with laws of mechanics, have been studied in order to apply water-power to advantage in the construction of wheels to turn machinery.

The best mode of applying the power of water to wheels is found to be when the wheels are placed vertically, having, of course, their axis of rotation horizontal. The different wheels are designated according to the part of the periphery or circumference on which the water acts,—*undershot, overshot, high* and *low breast* wheels. The *undershot* wheel (fig. 87) is above the stream, dipping in it below, and the running water ope-

Fig. 87.—Undershot wheel.

Fig. 88.—Overshot wheel.

rates against a series of flat boards placed around the outside,

by which it is driven round. The *overshot* wheel (fig. 88) is that in which the water flows upon the wheel from a higher level than the wheel, and, falling into buckets or recesses, by its weight presses the wheel downwards, which, emptying in its descent, returns upwards light; and thus having a light and heavy side, motion is given to the wheel. A *breast* wheel is when the fall of water is lower than the diameter of the wheel; this pouring on the wheel above its axis, it is called *high breast*; and upon a lower part of the circumference, *low breast*. It must be obvious that it depends chiefly on the diameter of the wheel whether the water falls above or below the axis. In these wheels both the momentum and weight of the water act in creating motion.

If water flowing from a mill-race be 3 feet broad and 2 feet deep, at a rate of 4 miles an hour, in an undershot wheel, multiply 3 by 2, that is the depth and width, this is 6. For the 4 miles which flow in an hour we have 21,120 feet, this divided by 60 gives 352 feet per minute; then multiply 352 by 6, and the number of feet of water passing under the wheel per minute is 2112. But as the pressure of water is only equal to half the area of the float, the whole pressure per minute will be the half of 2112, or 1056 feet; and as a cubic foot of water weighs $62\frac{1}{2}$ lb., its labouring force is 66,000 lb. per minute, or 3,960,000 lb. per hour. But in an overshot wheel there are great advantages, as the weight of the water acts on the wheel through a larger space; and in the breast wheel there is the advantage of a perpendicular column of water.

Much ingenuity is exercised in the form and position of the buckets to receive the water; also the angle at which the water should be laid on has been a matter of discussion. In this country it is thought to be best at $52\frac{3}{4}$ degrees from the summit; while the French consider 60 degrees, that is, 30 degrees above the horizontal plane passing through the axle of the wheel, as most productive of power.

Rennie increased the width and diminished the depth of the buckets of water-wheels; he also applied the descending shuttle by which the flow of water is regulated over the upper edge, so as to obtain the full benefit of the fall, instead of passing under the shuttle, whereby some of the fall was lost; and by augmenting the velocity of the periphery or circum-

ference from 3 feet to 5 feet per second, realized nearly 75 per cent. of the power.

Of the Motions of the Sea.

The movements of the mighty mass of waters which extend over by far the larger moiety of the surface of our earth, are many and varied in nature, but all of vital importance to those who have to journey on its surface, as they are frequently productive of danger to the frail fabrics to which these must needs trust themselves. The constant movements of the ocean are tides and currents; the accidental, waves and storms. The diurnal flow and ebb which we call *tide* has its cause in the attraction exerted by the heavenly bodies, especially the sun and moon, on the loose mass of liquid forming the ocean. The moon has the most to do with these tides, being so much the nearest to the earth. Their daily recurrence and occasional increase depend upon this satellite, as well as on the motions of the earth and sun, their variation being caused by the varying astronomical relations of these three orbs.

Owing to its peculiar geographical position, the Mediterranean sea has no tide, but rushes into the Atlantic through the Straits of Gibraltar in the direction of the moon's motion from east to west.

Besides the tidal motions, there are certain oceanic currents of the greatest importance in navigation. These depend upon special local causes continually in action—as, differences of level, the pouring in of great rivers, the heat of the tropics and the cold of the poles, opposition by masses of land, the rotation of the globe, and certain prevalent winds.

The heat of the equator and the movement of the globe cause an immense mass of water to be directed against the coast of America, striking against the shores of the Gulf of Mexico; this current is deflected eastward, and taking a direction towards the British islands, forms the great Gulf-stream. Oceanic currents which meet in an oblique manner, may form dangerous eddies or whirlpools—as those off the coast of Sicily, so dreaded and so exaggerated by the timid mariners and romances of ancient times under the names of Charybdis and Scylla; or that more really terrible one off Lofoden in Norway, the Maelstrom. These vortices depend much also on a certain concurrence of wind and tide. And it adds to a storm in

such regions an additional terror of no mean import, to know that a ship which is drifting helplessly towards a certain spot of the ocean, will, as soon as it arrives there, be sucked down by the remorseless eddy into the very bowels of the deep.

Waves are accidental movements of the surface of the sea, because they cannot be said to exist when the atmosphere is perfectly still: the surface is then calm. But wind, or any motion of air, produces a perturbation of a surface of water, which is greatest when that surface is extensive. The wavelet caused by blowing on a tumbler of water, or that which spreads circularly from a fall of a stone into a mill-pond, are explained in the same manner as the imposing foam-crested elevations beheld in the sea as it rushes towards the shore. There are successive and continuous intervals of action and reaction. A part of the surface is depressed and pushed forward by the wind, in front of it the water heaves up. Reacting in obedience to the laws of gravitation, the depressed part rises, the elevated ridge falls. The wind, still blowing, causes a second reaction, and so on. The appearance of the whole surface is as if a number of waves *moved onward* in one direction.

But the water that forms a wave does not necessarily move onwards; it is only the surface which rises and falls rhythmically, just as when we spread a long carpet or piece of cloth on the floor, and shake it from one end,—the mode practised in dramatic representations of the ocean's waves. The motion of the waters moving progressively onwards, on arriving at a beach they curl over, and the communicated force they contain expends itself by friction against the shore. The average height of a wave is about 12 feet, added to which is the hollow of 12 feet, or as it is called "trough of the sea," giving an appearance of 24 feet in height. During some storms in the Atlantic, Dr. Scoresby measured waves 43 feet above the level of the hollow occupied by the ship, and states that the average waves are 15 feet high, while the peaks of crossing or crests of breaking seas would shoot up 10 or 15 feet higher. From crest to crest he estimates the mean distance at about 559 feet; the rate at which they travel, about 790 feet in sixteen seconds of time; and the breadth of the waves 220 feet.

Thus does science measure and mark nature in her calmest and stormiest moods. It will be seen from what we have stated, that when a vessel is made of an extraordinary length,

its stem and stern may reach from wave to wave, and the midships be left unsupported by the sea, which must endanger the safety of the vessel, it being then apt to *break its back*, as nautical men say. But the machinery of large steam-vessels rests on bridges of iron that span the vessel's length, giving strength to the midships.

Voyagers to Madras tell us of the vast waves continually breaking on the coast, which create a dangerous surf, extending some distance from the shore. As there are no harbours, the mails, and sometimes passengers, have to be landed in little rude vessels, called catamarans, that are driven through the surf; the boatmen are often washed off them, but being accustomed to their management, and practised in swimming, they regain their places, and preserve their cargo, with wonderful skill. A small river runs from the shore into the sea; and many an attempt has been made by the engineers visiting this important presidency, to render this available for the purposes of a harbour, but as yet fruitlessly. Captain Chisholm having observed a balk of teak wood, that had been driven by the force of the ocean into the shore, withstand the raging of the surf for some years, contrived a pier of timber to extend beyond the broken water, by which passengers and goods might at all times be landed.

When the ocean tide meets the rapid stream of a powerful river, the former, being the stronger, rises up like a wall, and rushes with irresistible force along the coast. This is named the *bore*; it often causes great injury to shipping; it is common near the mouths of the Ganges, whence its effects are felt to a considerable distance. On a smaller scale, it forms a familiar phenomenon in many British rivers.

On Machines for lifting Water.

The method of drawing up water by exhausting a tube of air, as in the common pump, will be presently treated of in the chapter on PNEUMATICS. We may now speak of some simpler machines that do not call into operation the agency of the atmosphere.

The most pristine mode of which we have any knowledge is that at present employed by the market-gardeners around London. It consists of a long pole placed horizontally and balanced on an axle at the top of another long pole, or an ad-

jacent stem of a tree, standing upright. The bucket, suspended over the well from a rope attached to one end of the

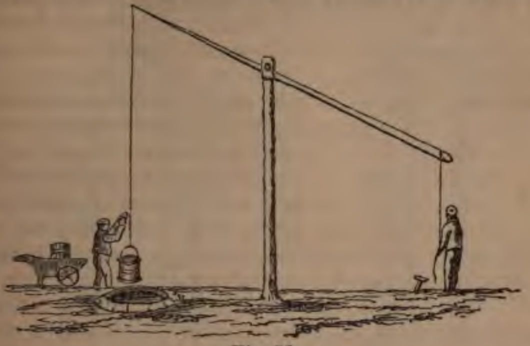


Fig. 89.

horizontal pole, being dropped to the bottom and filled, in the action of which the end of the pole where the bucket is fixed sinks down and the other end rises, a man having hold of a short rope fastened to the part of the pole now elevated, pulls it down, and the bucket rises from the well (fig. 89). This is a speedy method in comparison to the winch and axle, and answers excellently where the water is at no great depth.

The commonest mode of raising water from wells is that of coiling a rope by means of a winch or handle round an axle. The power required to lift the water is as the circumference of the axle to the circumference of the circle described in turning the handle. If the latter be twelve times the size of the former, then one pound at the handle will raise twelve pounds at the axle; therefore the less the axle, and the longer the handle, the easier is the work. Those who have tried this mechanical operation are aware, that if the well be deep the rope or chain has to coil again and again over the axle, and as the bucket approaches the top the work becomes harder, and more strength has to be applied. This arises from the rope or chain increasing the size of the axle, and lessening the difference of the circumference of the circle of the handle in proportion to the axle.

The accompanying diagram (fig. 90) shows a method of raising water in a somewhat similar manner to that of dredging up the mud and gravel at the bottom of rivers. A series of

buckets, *c c c c*, are attached to a rope or chain which passes round two pulleys, or rather wheels, *a* and *b*, the lowest being sunk in the water that is to be raised. On turning a

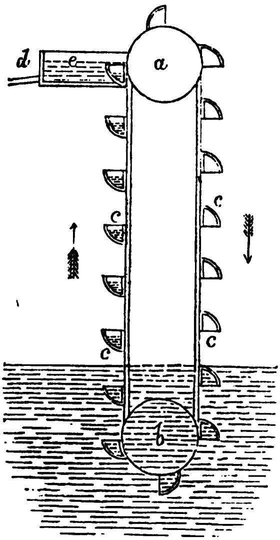


Fig. 90.—The Bucket-machine.

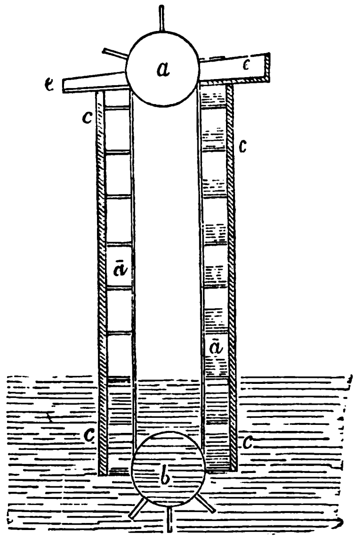


Fig. 91.—The Chain-pump.

handle fixed in the wheel *a*, the buckets rise on one side, and descend on the other in the direction of the arrows. The buckets that are raised up are full of water, and on arriving at the wheel *a*, in turning round, it is turned out into the trough *e*, and led away by the pipe *d*. This is called the "Bucket Machine."

The plan we have just described is improved upon (fig. 91) by having flat boards attached to the rope or chain instead of buckets. Passing over the wheels *a*, *b*, these are made closely fitting to a long tube or box *ā ā*; on the boards rising from the wheel *b*, they carry the water above them in the manner of a piston of a pump with a closed valve; and on reaching the trough *e e* the water flows in, having borne more upwards than could have been done by a proportionally sized machine with buckets. They are found to answer well in ships, and are called chain-pumps.

An extremely simple mode of raising water in opposition to its gravity is the following:—A rough hair flat rope *f f* (fig. 92) passes over two wheels *a*, *e*, when by the friction created by rapidly turning the handle *c*, a quantity of water is raised to the trough *b b*, from whence it is discharged by the spout *d*. The ascending rope passes through a wide aperture at the top, but on the opposite side is squeezed through a small tube, by which the water is retained. Instead of the handle a band may be affixed, which is moved by steam-power. These machines are found to succeed when the height the water has to be raised does not exceed ten feet.

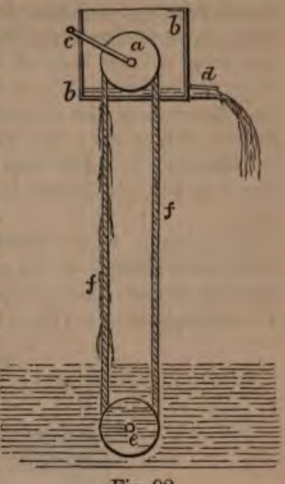


Fig. 92.

The fens of Lincolnshire are considerably below the level of the sea, and are known to be saturated with water; many are the contrivances to drain the land, so that it may be rendered subservient to the purposes of agriculture. The most successful method is that of water-wheels (fig. 93). One of these being

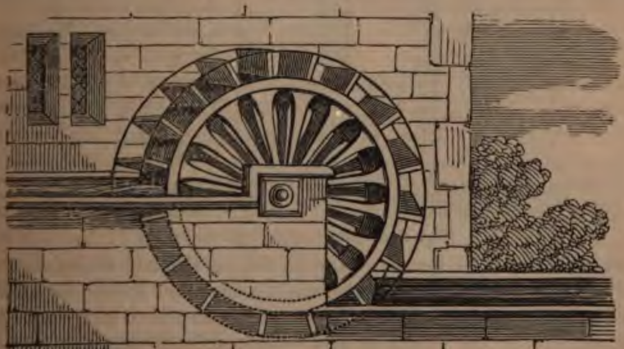


Fig. 93.

placed in the water, and having floats or buckets around its circumference, not radiating from the centre, but as tangents in a small circle set in motion by one of Boulton and Watts' engines, can raise a large body of water four feet in height; at some distance on this higher elevation a similar wheel is placed, and thus throughout the district the water is gradually raised four feet at each wheel: the effect of this system has been so extraordinary, that the land in the country of the fens is now found to be eight inches lower than it was twenty-four years ago.

The visitors at the Great Exhibition of 1851 were struck with astonishment at the operations of the centrifugal pumps there in action. The action of such a machine is as follows:—If we suppose *a a* (fig. 94) to be the well from which the

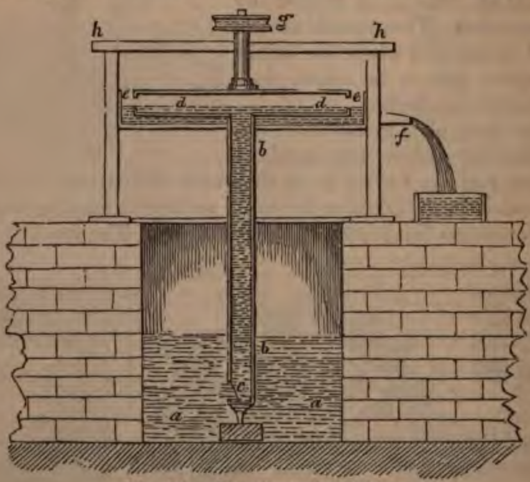


Fig. 94.—The Centrifugal Pump.

supply is to be drawn, let a pipe *b b* be allowed to rotate on a centre at the bottom of the well, as at the "step" shown in the drawing, and have motion communicated to it by a band passing over the pulley *g*, and connected with a prime mover near the top of the vertical pipe *b b*; let two arms or pipes *d d* be placed communicating with the interior of *b b*, but at right angles; let these arms be open at the ends *e e*, and be above a

trough supported by the frame h h. On filling the tube b b with water, which is prevented from passing out by the closing of the valve c at the aperture at the bottom of the pipe b b, and turning it by the pulley g, the arms d d rapidly revolve, the centrifugal action will throw out the water by the ends e e into the trough or box, and this will pass off by the pipe f; as the water is withdrawn from the top of the vertical tube by being passed through e e, more water is drawn through the valve c, and by this means the supply is continuous so long as motion is imparted to the tube; the valve c closing whenever the tube is stopped, prevents water passing out, and consequently does away with the necessity of filling the tube each time it is required to be worked.

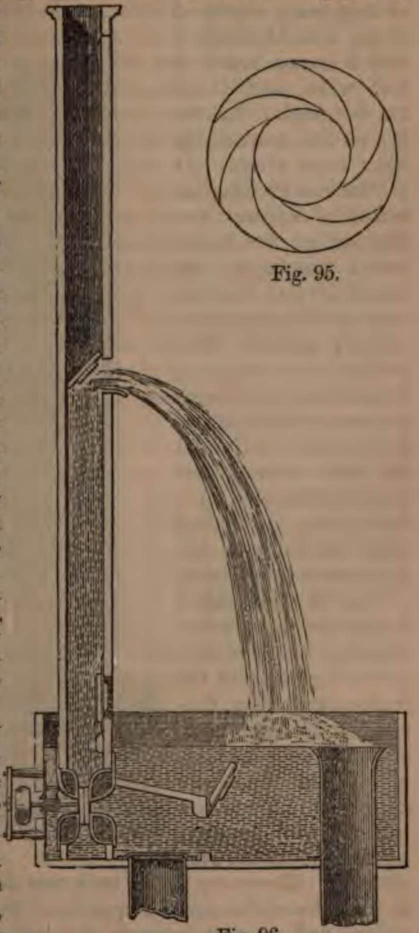


Fig. 95.

Fig. 96.

Amid the machinery at the Great Exhibition, towering above other objects by rising to the roof of the building, was a wooden pipe, in appearance like a chimney-shaft, from which, sometimes about half-way up, at other times near the top, rushed a broad

sheet of water which engaged the attention of the visitors; this was Appold's Rotary or Centrifugal Pump.

Fig. 97.

The outward portion of this pump consisted of an upright shaft, 7 feet 6 inches broad, 1 foot wide, and about 22 feet high; fig. 96 is a vertical section, fig. 97 a front view. At the bottom of this was a tank of water. The first outlet for water was 1 foot high; the second 10 feet, with an area of 576 superficial inches; and the third 17 feet above the surface of the water, with an area of 1008 superficial inches: each outlet had valves; the middle one is seen open in fig. 96. A vertical pipe carried off the water to a lower tank.

Fig. 95 represents a hollow disc or cylinder, 12 inches diameter, with a round opening in the centre, 6 inches diameter; the rim measured 3 inches in width, which was open all around it; the other parts of this disc, excepting the centre, were enclosed. The water in the tank was drawn into, or received, at the sides of the circular opening of the disc of 6 inches diameter, and passing between the half-circular blades to the rim, was thrown into an iron case enclosing the disc; this

case had an opening at the top of 63 superficial inches, through which the water was cast upwards.

Now we know if we turn a mop that has been dipped in water quickly round, the water is driven off to a distance proportionate to the velocity given in the trundling; and this it will be seen is the principle of the centrifugal pumps. We may also illustrate it by corn dropped in the middle of two stones when in revolution; the flour rushes off to the edges: hence, when water is thus propelled from a centre, if not allowed to fly off, by being confined in a case, wherever it can find an outlet, there will it go; if an upright tube, it rushes up that as a means of escape. The disc was placed upright at the bottom of the shaft, with a spindle passing through its centre, the other end of which projected at the back part, and had on it a wheel, 12 inches diameter; around the wheel was a band connected with steam machinery, having an $8\frac{1}{2}$-inch diameter cylinder of 2 feet 2 inches stroke. With a pressure of steam of 28 lb. on the square inch, giving a velocity to the piston of 250 feet per minute, the disc made 800 revolutions in a minute; which, if we multiply by the circumference, that is, three times and nearly one-seventh of the diameter, in even figures, 3 feet $1\frac{3}{4}$ inch, the velocity of the rim would be equal to 2516 feet 8 inches in a minute (really 2512 feet). If we desired to know the superficial area thus produced for the outlet, the way is to multiply the number of feet, 2512, by the width of the disc, 3 inches, that is, 7536; divide this by 12, to reduce to feet, and the result is 628 per minute. To return to the disc; it was stated to be 12 inches diameter and 3 inches deep. A cylinder 1 foot high and 1 foot in diameter contains 1357 and a fraction cubic inches; this must be divided by 4, as the disc is only the fourth of a foot deep, and the result will be a little over 338 inches; a gallon contains over 277 cubic inches; hence we find that the disc will hold one gallon and nearly a quarter. So that, if the disc throws this quantity of water from it 800 times a minute, it delivers in that space of time 1000 gallons.

Mr. Appold states:—"From the results of various experiments, it has been found that the loss of power would not be more than thirty per cent. The centrifugal force is not so much in the large diameter, on account of the water moving more in a straight line; but that is compensated for by the

force being applied to a greater depth of water, being 5 feet in the 20-feet, and only 3 inches in the 1-foot. 159 revolutions with the 1-foot will raise the water 1 foot higher, without discharging any; 318 revolutions, 4 feet; 636 revolutions, 16 feet; and 1272 revolutions, 64 feet high. The highest elevation to which the water has been raised with the 1-foot pump is 67 feet 8 inches, with 1322 revolutions per minute; being less than the calculated height, which may be accounted for by leakage with the extra strain.

"While the 1-foot pump is raising 8 tons of water 5 feet 6 inches per minute, there is no greater strain on any part of the pump than 160 lb. on the 6-inch drum, which is equal to a leverage of 3 inches. It will pass almost anything that is small enough to go through, there being no valves. A quantity of walnuts (about half a gallon) were thrown into the 1-foot pump all at once, when it was at full speed, and they passed through without breaking one."

There are other methods of raising water, which, more for their ingenuity than utility, we may notice here. One is named the "Horn drum:" *c c c* (fig. 98) are arms bent in the manner that gives the appellation to the machine; these form scoops, and radiate from a hollow axle *a*. When the wheel is set in motion, the scoops, dipping into the water *b b*, raise some up, which, as the wheel rotates, falls towards the hollow axle, and, there being holes in it, passes to the middle, from whence it flows into the trough *d d*, and is then conveyed away as required. It is to be seen in operation on the banks of the Nile, one of many such sights showing that a

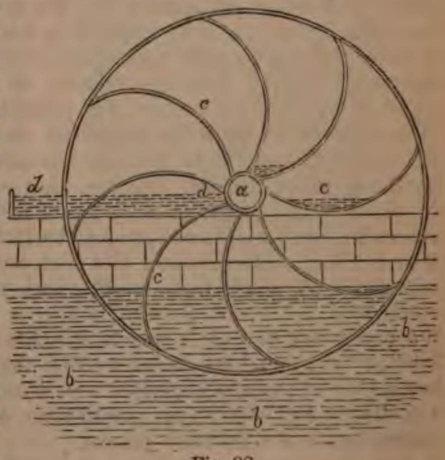


Fig. 98.

people once the source of civilization and science, are now outstripped by the energy of nations lately risen into existence.

The Persian wheel is a modification of the preceding one. It is used in running streams, and has floats on one side, similar to those of the paddles of a steam-vessel, by which motion is given to the wheel. On the wheel *a a* are suspended a number of buckets *c c c* (fig. 99), by means of strong pins; on the wheel

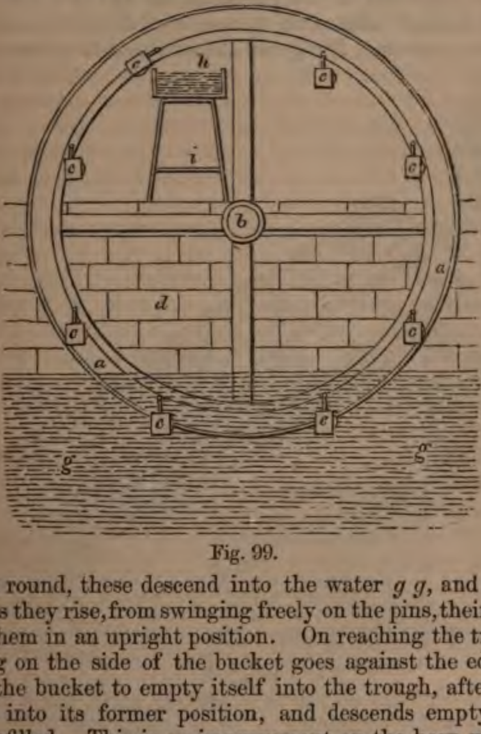


Fig. 99.

turning round, these descend into the water *g g*, and become filled; as they rise, from swinging freely on the pins, their weight keeps them in an upright position. On reaching the trough *h*, a spring on the side of the bucket goes against the edge, and causes the bucket to empty itself into the trough, after which it falls into its former position, and descends empty, to be again refilled. This is an improvement on the horn wheel, as the water is raised nearly to the top of the wheel, instead of only to the centre.

There is another ancient method, even to this day found

serviceable in particular cases, which, from its name, would lead us to date it as far back as the famous philosopher Archimedes, as it is called his screw.

The Screw Pump is generally formed in the following manner: A cylindrical shaft (on which the pump revolves) has one or more grooves cut round it in a spiral direction, into which are fixed a series of boards which form the thread of the screw; the outer edge of these boards is sunk into spiral grooves formed into the inner side of the cylindrical casing; the pump is then tightly secured with iron hoops, and fitted in a frame in which it revolves. The great advantage of this form of pump

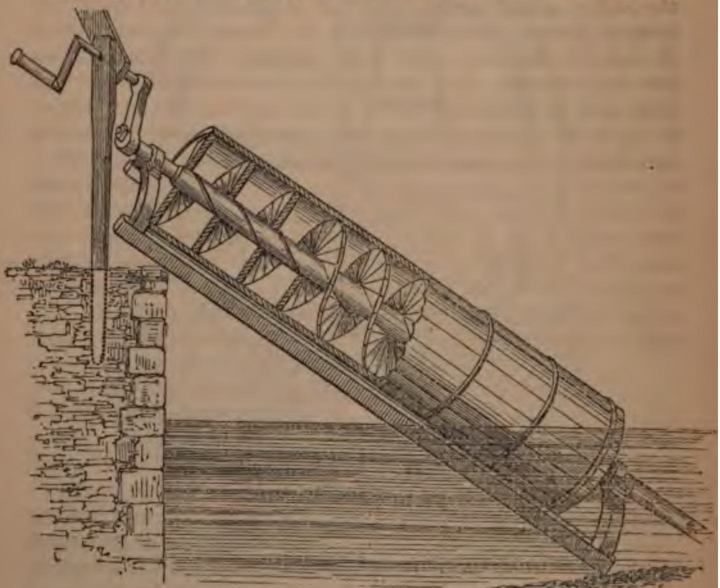


Fig. 100.

is that it contains no valves or moving parts, and will therefore raise water containing a large quantity of sand or other material held in suspense, which would rapidly wear out valves or prevent their acting properly; the water being raised by a simple lift, and not by centrifugal force, the pump can be worked efficiently at any speed (fig. 100).

Suppose water to be running from the lower orifice of a pipe placed vertically, and to be suddenly stopped by the instant insertion of a plug or other contrivance, a certain shock at the lower end of the pipe will be felt; and if the height of the pipe be great enough, the pipe in all likelihood will be burst. The reason of this shock being sustained in this manner is, that the downward motion of the water being suddenly stopped, and the momentum or force of the column of liquid being very great, the plug is struck with as much violence as if a solid bar of iron, of the same height and diameter, were falling at the same velocity on the plug; this momentum of the water, acting on any body placed so as to arrest a quick flowing stream, is exemplified in the household water-pipe. If water is allowed to flow through a pipe leading from a cistern for some time, and then suddenly stopped by turning the stop-cock, a shock is sustained, sufficient in some instances to burst the lower part of the pipe. This pressure of an arrested flow of water has been made available for the purpose of raising water from a low to a high level; the contrivance by which this is effected is known as the "water-ram." It was invented by the celebrated Montgolfier, though the principle had been previously explained and exemplified in this country by Professor Millington. Suppose that a spring of water *a* (fig. 101), or a small stream placed at a little distance above the ordinary level of the ground *b*, as on the face of a knoll or

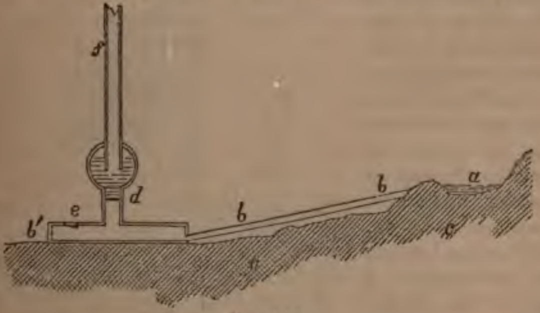


Fig. 101.

small hill *c c*, run to waste through a channel leading to and passing off by the level ground beneath it. The water is con-

fined in the first place to a pipe *b b*, instead of the open channel. This pipe communicates at the lower level *b′* with a horizontal pipe or chamber *e*, at the end of which is placed a valve; this valve, when drawn upwards, effectually closes the aperture through which the water escapes when the valve is down. The valve *e* is made so heavy, or weighted by small weights, that the stream has to run some time to acquire sufficient force or momentum to shut it. As soon as the valve is closed by the force of the descending water, the water passes up the tube *f*, in which there is a valve opening upwards; the water in the main pipe, in consequence of the quantity passing into the chamber *d*, becomes stagnant, and allows the valve to fall, by which a portion of the water from the stream escapes. As soon as the water acquires sufficient momentum from flowing through the valve-aperture, it shuts the valve, and a portion of the water is sent up the pipe *f*, and into the round air-vessel, from which it is sent in a continuous stream, and is prevented returning by means of a valve. Thus, if we suppose the stream in fig. 101 to be situated on the face of a hill or cliff, beneath a dwelling-house, a portion of the water could be sent up for household purposes by the pipe *f*. In fig. 102 we give an illustration of the improved form of water-ram now fitted up, in numerous instances by an hydraulic engineer, for the supply of water to houses, &c. situated as above. *a a* is the pipe leading from the source of supply to the escape-valve, opening and shutting at intervals,

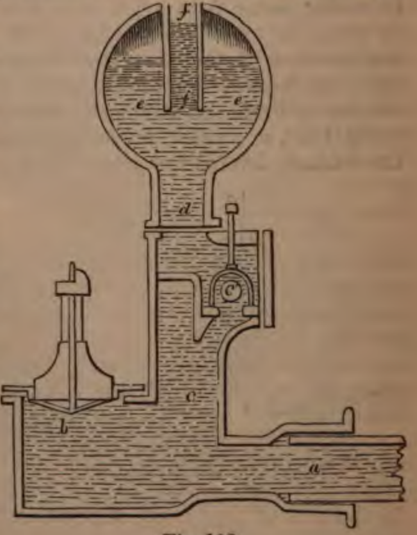


Fig. 102.

as described; *c* the passage to the valve *c′*, which opens inwards,

the play of which is regulated by means of the screw, as in the diagram; *d* the pipe leading to the equalizing air-vessel *e e*, from which the water passes up to the place of delivery by the pipe *f f*. As the water in the air-vessel is found in process of time to absorb the air contained in the vessel, the working of the apparatus is prevented by the want of the elasticity necessary; this difficulty is obviated by applying to the air-vessel a contrivance called "a snifting valve," which admits a certain quantity of air at every stroke.

Before leaving this subject, we would notice that if a stream of water 2 inches wide were allowed for one second to flow down a pipe 30 feet long, having a slope of 6 feet, upon the forward pressure being arrested by a stop-cock, the momentum it would have acquired would drive half a pint of water up a pipe 40 feet high. This operation of closing the tap or valve every second, on the above scale, would raise 3 gallons 6 pints in one minute. A knowledge of this principle led an ingenious gentleman, Mr. Armstrong, to erect and work cranes at Newcastle-upon-Tyne by the pressure of the water in the common pipes that supplied the houses of the town. The machinery is below the surface of the street, therefore both out of the way and hidden from sight or accidents. There is a dial with handles or indicators communicating with valves, to regulate the pressure of the water below, by which the raising, lowering, or stopping of the machine is managed with the greatest facility. The simplicity, power, and cheapness of these hydraulic cranes have met with general approval.

It is related that a farmer who lived near a river where a bridge was much needed, requiring water to irrigate his land, hit upon the following expedient:—He built a bridge that moved on a central axis, and divided it into two longitudinal sections, that is, through the middle of the roadway; and each part was so balanced, that when one end was down the other was raised. When a traveller came to the bridge, he was sure to find one of the sections on a level with the road and the other raised; of course he walked on to that which was level, and after passing the centre his weight brought the other end down, and raised that on which he first stepped. To the ends of the bridge were affixed pumps, and this action of rising and falling pumped the water into his reservoirs.

Fig. 103.

CHAPTER VI.

PNEUMATICS.

The business of this portion of our work is to treat of the mechanical properties of elastic or aëriform fluids, as to their weight, density, compressibility, and elasticity — the word pneumatics being derived from the Greek word *pneuma*, breath or air.

Nature of Aëriform Bodies.

Aëriform bodies, elastic fluids or *gases*, constitute a very distinct form of matter. *Solids* are distinguished by a strong attraction of aggregation, which keeps them together in a firm mass. In *liquids*, also called *non-elastic fluids*, this force is so much weakened, that the particles slide freely over one another, and spread indefinitely in a horizontal direction.

Between solids and liquids there are many intermediate steps, as of soft and viscid substances; but between liquids and gases there are no such gradations. The transition is sudden from one to the other. Between the particles of a gas or vapour there is little attraction of any kind—rather repulsion. The approximation of such atoms depends more upon pressure and weight, either of themselves or surrounding matter, than on any mutual attraction.

A gas or vapour moves freely in all directions. It is elastic,

and distinguished by the two properties of *expansibility* and *compressibility*. It expands in all directions, and enlarges just in proportion as the pressure upon it is removed. It may be compressed to almost any bulk, by an increase of that pressure.

Aëriform bodies are transparent, generally colourless, of extreme tenacity and low density, consequently invisible. There are three groups of them which differ in a marked manner in their physical properties. (1) Air, and the two chief gases which compose it, are *perfectly elastic*, and cannot be made to assume the fluid state by any degree of pressure. Their bulk is in inverse ratio to this pressure. (2) Others, as carbonic acid gas and chlorine, are reduced to the liquid state by great pressure or an extreme degree of cold. (3) The third group is that of vapours (as steam), which at the ordinary temperature and pressure of the atmosphere are liquid, but become gaseous, and exhibit the properties of gases when subjected to a certain increase of temperature or diminution of pressure.

The Atmosphere.

This is that aërial fluid, together with its clouds and vapours, in which man, animals, and vegetables exist. Air is so light and thin, that when at rest it cannot be felt; so transparent, that it cannot be seen. That air is a substance may be heard when a switch is passed rapidly through it, or a storm howls. It is felt in moving a fan; its effects are seen in the current blowing about dust or leaves, and the hurricane prostrating trees—in the whirling windmill, and the sails of the stately vessel—in the rapidly-ascending smoke, which rushes aloft like a light stick from the bottom to the surface of water—in the soaring eagle, sustained by it in his aërial flight, and in the balloon, ascending above the clouds, or driven along by its currents. Man breathes it about twenty times every minute, or 1200 times in an hour; in quantity, about 18 pints a minute, or 1067 per hour, or 57 hogsheads 1 gallon 7 pints in a day. Without it in a pure state, he would die; for it keeps the machinery of his system in action, gives the vital principle to his blood, and warmth to his body. This applies alike to animal and vegetable creation; were there no air, existence must cease. The vegetable kingdom spreads forth its delicate porous leaves, to breathe that portion of air rejected by man,

and gives out, in the wonderful economy of nature, that portion beneficial to animal life. Thus is there incessantly going on an interchange of matter to suit each peculiar condition of creation.

If a vessel capable of holding a cubic foot of air be emptied by means of an air-pump, it will be found to weigh 535 grains less than when filled with air; the same vessel filled with water, will weigh nearly 1000 ounces. Therefore, as 535 grains are little more than an ounce, a cubic foot of water weighs about 814 times more than a cubic foot of air. In calculating the specific gravity of air or gas, 1000 parts of common atmospheric air are taken as the standard.

One thousand parts of atmospheric air, on an average, consist of—

Nitrogen . .	788 parts.	Aqueous vapour . .	14 parts.
Oxygen . .	197 „	Carbonic acid . .	1 „

And the specific gravity of these gases, assuming air as 1000 (and giving in place of the aqueous vapour one of its components, hydrogen), is as follows:—

Nitrogen gas . .	972	Hydrogen gas . . .	69
Oxygen gas . .	1111	Carbonic acid gas . .	1529

Atmospheric air is not a chemical compound, but a mixture in which the carbonic acid and aqueous vapour are merely accidental, not constituent parts, occurring in different quantities at different times.

Among the fifty or sixty elementary substances now known, the two chief gases of the atmosphere, in various combinations, act a most important part, which will excuse our digressing by naming some of the substances constituted by them.

Oxygen combined with *hydrogen* forms water; if an electric current be passed through water, it is resolved into its gaseous elements hydrogen and oxygen, which may be collected in separate utensils. If these gases are once more mixed, and a spark of electricity sent through them, a loud report ensues, and they have again become water. The proportion in water is 8 of oxygen to 1 of hydrogen. When oxygen is abstracted from atmospheric air, animal life ceases; without it respiration cannot go on, nor will fire burn; it is found in the ocean, the air, and in most solid substances. Oxygen and nitrogen, in various proportions, form atmospheric air, laughing gas, and

aquafortis; with sulphur, oxygen forms sulphuric acid or oil of vitriol; with carbon, carbonic and oxalic acids; with lead, it forms red-lead; with metals, it forms certain compounds, called oxides, dry, earthy-looking powders, with entirely different properties.

Nitrogen constitutes about three-fourths of the atmosphere, and one-fourth of animal flesh.

Hydrogen is the lightest of the gases: combined with nitrogen it forms ammonia; with carbon street gas; and when mixed in certain proportions with the air that issues from the fissures in coal mines, becomes highly explosive, and being accidentally ignited is often the cause of many lamentable accidents.

Carbonic acid, formed of carbon and oxygen, is more than one-half as heavy again as atmospheric air, and may be poured from one vessel to another. To breathe it is instant death; it is produced from burning charcoal. It collects in brewers' vats, and has been the cause of many fatal accidents. It is the gas which makes soda-water, ale, &c. sparkling and brisk.

Oxygen, hydrogen, and carbon form alcohol, starch, sugar, and many vegetable productions. Oxygen, nitrogen, hydrogen, and carbon, constitute albumen, fibrine, gelatine, &c. of which animals are formed.

This gaseous body possesses, in common with all matter, *impenetrability*; no other body can occupy the place it fills. If we take a glass vessel, and invert it in water, we shall find that the water will not rise into it beyond a certain very limited space (fig. 104). The air, being elastic, may be compressed, but, the pressure being removed, it will immediately occupy its original space. The elasticity of the air may be proved by confining air in a bent tube (fig. 105), and loading one arm with different weights of mercury. The spaces into which the air will be compressed will be found to be inversely as those weights. Those weights measure the elasticity of the air, and prove the *law of Mariotte*, that the elasticities are inversely as

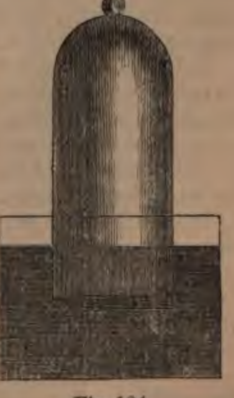


Fig. 104.

the spaces which the air occupies: the densities being inversely as those spaces, the elasticity of the air is directly as its density.

A volume of air occupying 100 measures, when compressed with a force of one pound, will be diminished to 50 measures when the pressure is doubled, and expand to 200 measures if the weight is reduced to half a pound. This law was first observed by Boyle, and more fully demonstrated by Mariotte. Subsequent experiments by Œrsted extended to air compressed with a force equal to 110 atmospheres, or 1540 pounds on every square inch, and the law is found to continue to this point,—from which we may fairly infer it to be general. Numerous experiments have been made with a view to compress atmospheric air into a liquid form; but although many other gases have been thus condensed, no such result has hitherto been obtained. Mr. Perkins stated that, under a pressure equal to 2000 atmospheres, he had succeeded in reducing air to a liquid; but there is reason for believing that the fluid obtained was no other than water separated from the air under compression.

Fig. 105.

The *elasticity* of air may be seen by pressing a bladder which is filled with it; the bladder thus pressed will give way under the weight, but upon being relieved it will immediately resume its former bulk.

If the piston of a common syringe be forced down when the pipe is stopped, the air will be compressed; on removing the pressure, the piston is forced back again. Air can thus be compressed into about 100th of its usual space. If the pipe be still stopped, and the piston drawn up, then the air expands by becoming less dense.

The truths of science were often demonstrated to the vulgar as mere toys, to excite the wonder of "children of a larger growth." Amongst those, we know of none more appropriate to our present theme than the little balloon floating in a glass jar nearly filled with water. The balloon is formed of glass, hollow, having a hole at the narrow end, from whence is hung a car. By placing it in water it floats, half appearing above the surface. Water is poured into the balloon until the specific gravity of the little toy is nearly that of water, and it

then floats in its liquid bath about midway. The jar is next closely covered with a piece of parchment, india-rubber, or gutta percha. On pressing this covering with the hand, the balloon descends; for the air being compressed, forces more water into the balloon, and causes it to sink. When the pressure is taken off, the air in the jar regains its former space by its elasticity; and as the air in the balloon follows this law also, it forces out the additional water, and ascends to its former position. Thus, with the hand on the top of the jar, the balloon may be made to rise or fall at the word of command, without, to the uninitiated, any apparent power to influence it. Should the balloon, however, in the experiment be forced down until it reaches the bottom of the jar, it remains there from the superincumbent weight of water overcoming the elastic power of the air contained in it; but by tilting the jar on one side, and thus lessening the weight of water, its first position is recovered.

This toy exemplifies the elasticity of air; as on the pressure being removed, the air resumes its previous space; also that air is a substance, and capable of compression; and as the balloon floats from having air in it, that it is light; it illustrates fluid support, pressure in all directions, and pressure as to depth; for the lower the little machine sinks, the lighter is the pressure required on the covering of the jar.

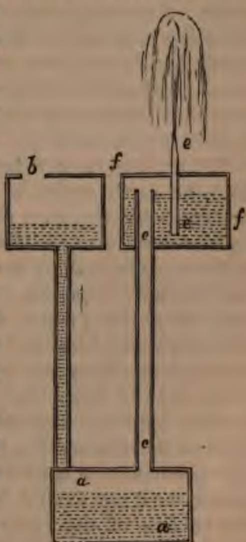


Fig. 106.

Amongst other such little contrivances is the fountain or *jet d'eau* of Hero, which illustrates the elasticity of air. The annexed figure will explain the *rationale* of the operation of this elegant toy. A vessel or air-tight box *a a* (fig. 106) is supplied with water from the box *b*; a pipe *c c* leads from the top of *a a* to near the top of another box *f f*, made air-tight. The water descending from *b* forces the air up *c c*, and acting on the surface of the water in *f f*, forces it out by the pipe *e e*.

Fig. 107 shows one of the many devices for making this philosophic toy ornamental. The water is placed in a vessel A, in a hollow stand B, and a small pipe C proceeds from the vessel of water up a hollow tube D. Water is then poured into the ornamental basin E, upon which it forces its way down the tube D, and pressing upon the air in B, the water in A rushes up the pipe C, and forms a beautiful jet of water. As the pressure is produced by the water in D, whatever length that tube is, such will be the height of the jet. Upon the water becoming exhausted from A, that which has fallen from E to B is removed, and A and E being replenished as at first, the action of the fountain is again commenced.

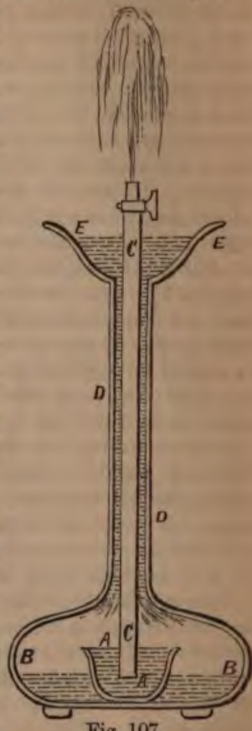


Fig. 107.

The air lies, as it were, in strata, from the earth upwards, the lowest stratum being the most dense; as in a pile of wool, that nearest the ground is more pressed than that above it, and gradually becomes less and less compressed as it nears the top. A curious philosophical fact results from this density of atmosphere, which is, in causing the rays of light to be bent as they approach the earth: thus they are more and more bent as the atmosphere becomes more and more dense. From this circumstance calculations have been made that the atmosphere does not extend further than forty or fifty miles above the surface of the earth; but its exact distance is unknown. That air must expand greatly, and consequently extend far, may be readily conceived, as by experiment it is found to possess considerable elasticity when only a thousandth part of its former bulk is left to occupy a certain space.

Air, like other fluids, is most dense at the lowest stratum, which is the level of the sea, as water is more dense the lower

we descend in it. At the height of three miles, that is the summit of Mont Blanc, the air is found to be only one-half as dense as at the level of the sea; hence when a human being arrives there, although his chest is fully expanded, yet the quantity of air being only one-half that which he has been accustomed to breathe, he may feel greatly incommoded. At six miles elevation the air is only one-fourth the density of common air on the earth's surface, and at nine miles only one-eighth. The "blue ethereal sky" of the poet owes its delicate tint to the atmosphere, and the clearer it is from clouds and vapour the more intense and beautiful is the colour. When Gay-Lussac ascended in a balloon to the height of 21,000 feet, nearly four miles, he found as he rose the blue gradually lessen, and a solemn, awful, black vault gradually presenting itself. The atmosphere holds suspended in it clouds and vapours, which, like milk or mud in pure water, float about and are moved by the various currents. These congeal into mist, rain, dew, snow, and hail. When the temperature of the atmosphere is high, moisture is absorbed; when lowered, it falls in the form of dew, rain, or snow. It has been ascertained that the atmosphere can never hold more vapour than would suffice for six or seven inches of rain to fall at one time.

Atmospheric Pressure.

Air or gas, like other fluids, presses equally in all directions, as may be felt in pressing upon a bladder of air, or filling a hydrostatic bellows with it instead of water. When the gasometer of a town is allowed to have additional pressure upon it, the lights in all directions suddenly start into a large flame, showing that the pressure is equal in all parts.

If a drinking-glass were covered by some such substance as a piece of bladder or thin india-rubber, and the air drawn out, a spring placed underneath would show that the weight pressing upon the covering was equal to 15 lbs. on every square inch of surface. If the covering were not supported, it would burst inward with a loud noise. The same experiment tried on the top of a high building would show that the pressure was not quite so great there as on the ground, and as a greater elevation is attained, the pressure gradually lessens. Thus a column of atmospheric air an inch square pressing on the surface of the earth is found to weigh 15 lbs., while a cubic foot

of it is in density or weight a little more than an ounce. A cubic inch of air one mile high weighs a little over 43 ounces; and the weight of 15 lbs., of the same density as at the surface, gives a column of air a little more than 5 miles in height. In drawing up the air-tight piston of a closed syringe, it requires a force of 15 lbs. to every square inch of surface of the piston, this force being necessary to overcome the resistance offered by the pressure of the atmosphere outside.

The air, then, presses with a weight of 15 lbs. on each inch of surface on everything upon the earth; and as the average surface of a man's body is estimated at about 2000 square inches, he bears a weight of upwards of 30,000 lbs., or about 13 tons. This weight would crush the human frame and prevent him from moving about, were it not for the law that the pressure of air is equal in all directions; the force of the outside pressure is equalized by the air contained within the body, and filling up all empty spaces. For a similar reason, a man who can scarcely carry a pail of water on his head, would not be crushed though he walked at the bottom of the sea. This pressure in all directions keeps things in their places; were it possible to empty a room of all the air it contained, the great pressure of the air would cause the walls and the roof to fall inwards. There are many simple but striking experiments by which the weight of the atmosphere may be illustrated; one is that of the *Magdeburg Hemispheres*:—

Fig. 108.

In 1654, Otto von Guericke, burgomaster of Magdeburg, publicly illustrated the pressure of air on solids. He made two close-fitting cups or hemispheres *a*, *b* (fig. 108), one foot in diameter, which he filled with water; then unscrewing the handle *d* off one of them, which communicated to the interior by a hole, having a stop-cock *c*, he pumped the water out; after

which he screwed the handle on again. This he presented at a public exhibition, when the emperor had six of his carriage-horses attached (by chains or ropes, as *e e*) to the hemispheres, but their strength could not pull them asunder. The resistance of the air was 15 lbs. on each square inch; yet when the stop-cock was turned and the air admitted, their separation was simple and easy.

Another interesting example of atmospheric pressure, is to fill a wine-glass with water, and, having placed a card over it, to invert it cautiously:—the glass may now be held as in fig. 109, the water having no support but that which it receives from the pressure of the atmosphere, without any being spilled.


Fig. 109.

Boys are in the habit of amusing themselves by making out of a round piece of leather a wet *sucker* or *cleaver*; to the centre part a cord is attached, which they press upon a stone, and, pulling the cord, if the stone be loose and not too heavy, they can lift and carry it about. There being no air below, the leather is kept in its place with a force equal to 15 lbs. on each square inch of the surface of the sucker, and will lift a stone in accordance with this power.

On this principle, that of shutting out the air from one part and having its pressure on another, arises the power of flies, and some other insects, to walk on ceilings and the upright glass of windows. Fig. 110 is a greatly magnified view of the sucker attached to the under surface of the house-fly's foot. The construction of their feet allows of a ready formation of suckers, and power at will of admitting the air to relieve them: it is estimated that a fly, when walking, in the course of a minute performs this


Fig. 110.

operation 10,000 times. The fishes called by the poor living at the sea-shore "clockers," adhere to rocks by a sucker on the underpart of their bodies, and when the tide has receded send forth a sound causing the uninitiated to search for a hen desirous of laying eggs, instead of which they discover a fish clinging to the rocks. Snails, periwinkles, and limpets possess this property.

The small black spot is intended to show the natural size of the fly's foot.

The *Atmospheric Clock* is a valuable application to a purpose of utility of the simplest of all natural laws. This clock possesses no mechanism, but indicates the hour by the regular descent of a column of mercury, and might, therefore, with equal propriety, be called the gravitating clock. There are two glass tubes, one within the other. The inner tube contains the mercury, and also atmospheric air. At each end this inner tube communicates by a small orifice with the outer tube, and consequently the mercury in its descent has to force the air out of the inner tube to the outer, and thus its rate of descent is regulated. This air escapes by the small orifice at the end of the tube, passes into the outer tube, and again ascends in it. When it reaches the top of the outer tube, it enters the small end of the inner tube, and thus, as fast as the air is forced out below, it enters above. This clock is in no way influenced, or certainly not to any appreciable extent, by the external air, as the outer tube is hermetically sealed. The gravitation of the mercury and the resistance of the air in passing through the orifice determine the rate of motion, and the division of the scale of hours is, of course, in accordance with it. It is not only an instructive toy, but a really useful invention.

Effect of Atmospheric Pressure on the Boiling-point of Water.

Every thing on earth, liquid and solid, is compressed by the atmosphere, and kept in its position and form; were this pressure removed, things would assume different forms, and many become gaseous, as is the case with ether and alcohol. To overcome this atmospheric pressure, and separate the atoms of matter in many fluids, man applies heat, and it is necessary to note the various degrees of heat required to be applied to different fluids to raise them to what is termed the boiling-

point. At the earth's surface, that is, where the mercury in a barometer stands at 30 inches, the heat required to boil ether would be by Fahrenheit's thermometer 190 degrees, to boil alcohol 174 degrees, water 212 degrees, oil and tallow 600 degrees, and mercury 650 degrees. By ascending a mountain the pressure of the atmosphere is lessened, and consequently less heat is required; for instance, at Quito, 10,000 feet above the level of the sea, water boils at 194 degrees, and on Mont Blanc only 180 degrees of heat are necessary to boil water, and by this test the actual height from the level of the sea may be ascertained; while in a diving-bell 68 feet deep in water it requires a heat of 272 degrees to make water boil.

The experiment of boiling fluids freed from the weight of the air has been tested by means of the air-pump, when it was found that water would boil at a less temperature than blood-heat by three degrees, and ether when six degrees above the freezing-point of water. This fact has, like most scientific knowledge, been rendered serviceable to man, most remarkably so in the distilling of drugs and the refining of sugar. By reducing the pressure of air, the pure medicinal properties of one have been preserved; in the other, a saving of material and superiority of quality.

Dr. Papin, crossing the Great St. Bernard, stopped at its famous monastery, when the monks, desirous of showing their hospitality, asked him if he had any preference as to the mode in which his food was cooked, when he replied that he preferred boiled to roasted meat. The brethren informed him that in this particular they were sorry they could not oblige him, as they found that meat could not be boiled properly at such an elevation. The doctor, returning to Paris, pondered over the subject, and the result was the invention of his famed digester. One of these digesters he had the satisfaction of presenting on another visit to the monastery, much to the delight of the pious fraternity.

The reason of this difficulty in cookery was, that the small amount of heat required to boil water at such an elevation was not sufficient to perform the necessary cooking operation, and the meat consequently was raw. The digester does not allow the steam to escape, and heat is accumulated until even bones are dissolved. For the sake of safety Papin adopted a valve

to his invention, so that it opened when the pressure of the steam was likely to be too powerful for the iron of which the vessel was constructed.

By removing the pressure of the atmosphere, we may make water boil in a bottle on placing it in a vessel of cold water. This is effected by pouring a little water into a Florence flask and holding it over a spirit-lamp until it boils; when the steam is briskly issuing from the neck of the flask, cork it tightly, and remove it from the lamp. The action of boiling will then have ceased, but on placing the flask in cold water we condense the steam and cause a vacuum, so that the liquid will boil with great rapidity; remove it from the cold water to the lamp, the boiling ceases; place it again in the cold water, and it again boils.

The cold water condenses the steam, and from the vacuum produced the water boils; when placed over the lamp the flask is filled with steam, there is no vacuum, and the water no longer boils, being prevented by the pressure.

Common Water Pump.

If we take a straw, place one end in water and the other in our mouth, then draw in the breath, we create a vacuum; the air in the straw first rushes into the mouth, and is followed by the water; this arises from the pressure of the air on the water forcing it into the part where a vacuum has been produced.

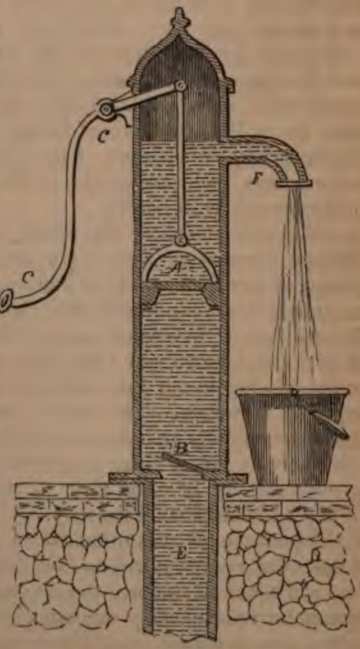


Fig. 111.—Common Pump.

On this principle the useful and common contrivance called the sucking-pump (fig. 111) is constructed. It consists of a hollow tube, having a close piston A, with a valve opening upwards, made generally of a piece of lead fixed to leather, and attached by a hinge. B is a hollow tight-fitting plug with a valve, the same as the other, but placed in a lower part of the tube. On pressing the handle C down, a vacuum is created between A and B; and the air pressing on the water, it rushes up the tube E, raises the valve B, which closes from its own weight, and that of the water above it. On A descending, by the handle C being raised, the water between A and B forces up the valve A, which, closing on the handle being pushed down, lifts the water up to the spout F, where it flows out. In doing this, a vacuum is again created between A and B, followed by more water; and thus the operation is continued as long as required.

Suppose a tube closed at one end were filled with water, and the open end then placed in a vessel of water, the fluid would remain in the tube at the height of 34 feet; this shows that the weight of the atmosphere on the earth is equal to a column of water 34 feet in height, or that of 34 feet of water surrounding the whole globe. From this fact in nature, a pump cannot be made to draw water from a greater depth; therefore when such a circumstance occurs as to render the operation necessary in a very deep mine, a succession of pumps is employed, averaging about 28 feet draught each; or another arrangement is resorted to, namely, the *Forcing Pump*. It used once to be supposed that water rose in a tube emptied of air, because "Nature abhorred a vacuum;" but this discovery that it would not rise to a greater height than 34 feet, led to a conviction in the mind of Torricelli the Florentine, that the weight of the atmosphere was the real cause.

The Action of Compressed Air.

We have already stated that the pressure of the air is equal at the earth's surface to about 15 lb. on every square inch, while it has a density or weight equal to 1 ounce troy for each square foot at its lowest stratum. Now this weight of 15 lb. on the square inch is called the pressure of *one atmosphere*. If 15 lb. to the square inch be added to compress air, it then fills one-half its former space, and its density is called a *double atmo-*

sphere. With twice 15 lb. then it is of triple density, and said to be *three atmospheres.* Just in proportion as it is compressed does its elastic reaction or force increase. In this manner a steam-engine or air-gun is spoken of as possessing a resisting medium of so many atmospheres. If we ascend into the heavens, or expand air by artificial means until it possesses only one-half of the density at the earth's surface, then it is spoken of as only *half an atmosphere,* and so on.

Fig. 112.

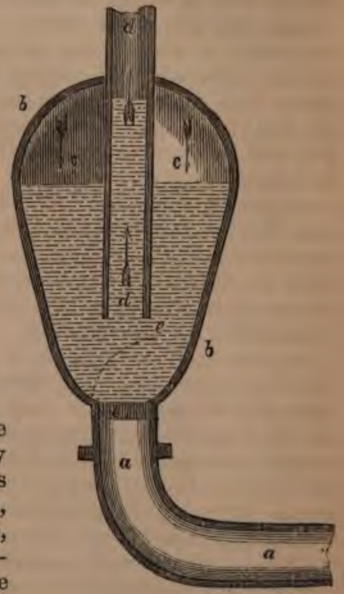


Fig. 113.

From a knowledge of the powers of compressed air many useful articles for domestic uses are formed, as table-lamps, shower-baths, and others, while a little refreshing parlour fountain adds to the charm of an adjoining conservatory. The last-named elegant jet is constructed in every variety of design, but the principle of action is the same in all. It consists of a vessel *a a* (fig. 112) partly filled with water, either air is then compressed into the vessel, or by means of an air-pump air is extracted, and upon turning a cock the water spouts up through a pipe *b* inserted in the vessel and reaching near to the bottom. A little stout cherub struggling with a dolphin is a

favourite device, the water issuing from the mouth of the captured fish.

The application of condensed air is of infinite service in many water-works having to supply large towns; for as filling the pipes direct by the working of pumps would cause it to flow in gushes, the water is pumped into a covered receiver, by which the air in it becomes condensed, and pressing on the surface, makes the supply uniform, and gives the necessary pressure to keep the pipes constantly charged.

Thus, suppose *a a* (fig. 113) to be the pipe through which the water is forced; it passes through the valve *e*, opening inwards to the vessel *b b*; the air accumulating in the upper part of the vessel at *c c*, presses upon the surface of the water, which sends it up the pipe *d d* in a continuous stream.

It may be remarked, that here the water is pressed into the receiver by means of what is termed a forcing pump, the power of which compresses the air. If the air be by this means condensed to a double atmosphere, the pressure would raise water 33 feet, if to a triple atmosphere 66 feet, and so it will increase in power to raise 33 feet for every additional atmospheric pressure applied. (For other uses of compressed air, see *Forcing Pump* and *Atmospheric Engines*.)

The Forcing Pump.

The simplest kind of Forcing Pump is shown in the annexed cut. It is merely an adaptation of the common sucking pump to the purpose of propelling water along a pipe. There is no valve in the piston *c* (fig. 114), but the water, raised through the suction-pipe *a* and the valve *g*, is forced by each depression of the piston up through the pipe *e e*, which is furnished with a valve to prevent the return of the fluid.

Fig. 114.

In other kinds of forcing pump, water is propelled by means of the *elastic reaction of compressed air*. We give a sketch (fig. 115), showing its application to a useful purpose, an inspection of which will make its operation easily understood. A well *a* in a street is provided with a pump-barrel *b b*, in which works a tight-

fitting piston; a valve opening upwards is placed at the bottom of the barrel at *c* and another at *e*, in the inside of the receiver, an air-vessel, *d d*. In the centre of the street, above the well, an ornamental pedestal *h h* is placed. In the centre of this the piston-rod *k k* of the barrel works, being operated upon by the handle *m*. A pipe *f f* proceeds from the air-vessel *d d*,

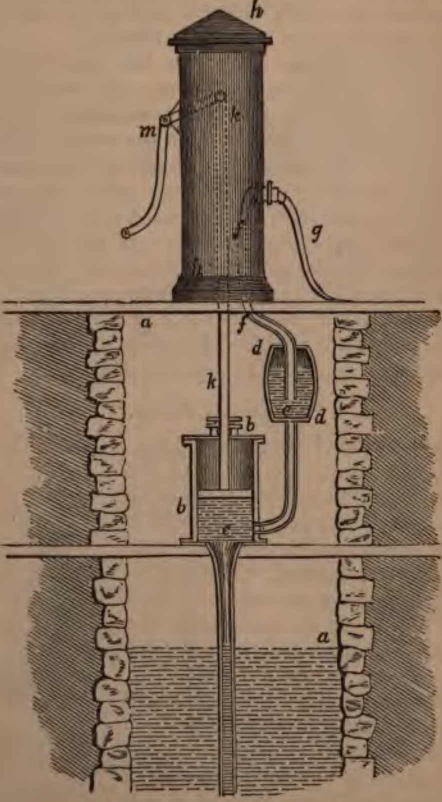


Fig. 115.—Forcing Pump.

and is terminated by a screw junction, to which the hose *g* is attached when required. The whole apparatus is designed for

a permanent force-pump, to be used in the extinguishing of accidental fires occurring in the street in which the apparatus is placed. Its operation is as follows:—On the handle *m* being depressed, the piston is raised, creating a vacuum in the lower part of the barrel, and causing the water to fill it, passing through the valve *c*. On the handle *m* being raised the piston is depressed. The valve *c* closing tightly prevents all egress through it: the water therefore is forced up the pipe leading to the air-vessel through the valve *e*. It is now by the pressure of the air in the air-vessel forced up through *f* and out at the orifice of the hose *g* in a continuous stream or jet. As the chamber *d d* contains air it becomes compressed by the water, and according to the force of its condensation does the water fly out of the pipe *f* and hose *g*. If the air be compressed one-half, it will press on the water with the force of a double atmosphere, and be sent the height of. 33 feet; and if to one-third its former space, the water will spout in a uniform stream to the top of a building 66 feet high, and so on, according to the pressure on the air by the water.

Fire-engines were used by the ancients, and introduced into England about the year 1700. They may be described as consisting of an oblong wooden chest, or cistern, along the lower part of which runs a metallic pipe, into which the water flows from a feed-pipe connected at the other end with a street-plug or reservoir of water. The water having entered, the interior pipe is elevated and forced into an upright air-vessel by two pumps, which are worked by men by means of long handles placed at the outside. From the air-vessel the water is forced into a pipe connected with the leather hose, and then directed against the burning edifice. If properly constructed they will throw a stream of water 130 feet in height; but it will be well to remember what we stated on the flowing of water through pipes, page 113, that an elevation of an angle of 45 degrees will throw water the greatest distance, which also applies to the engines we are now describing.

The following figure illustrates the action of the fire-engine. Two pump-barrels *b b* (fig. 116), are placed in the cistern *a a*, and surrounded with water to the level of *á á*. Each barrel has a piston *b b*, attached by rods *i i* to an oscillating beam *g g* working in the centre, moved by the handles *h h*. The valves *c c* open inwards to the barrels, and those marked *d d* to the

M 2

receiver *e e*. By the working of the barrels a continuous stream is projected through the pipe *k* in the centre of the receiver to which the hose is attached. It will be seen that the water, being pressed by the pistons into the receiver *e*, is

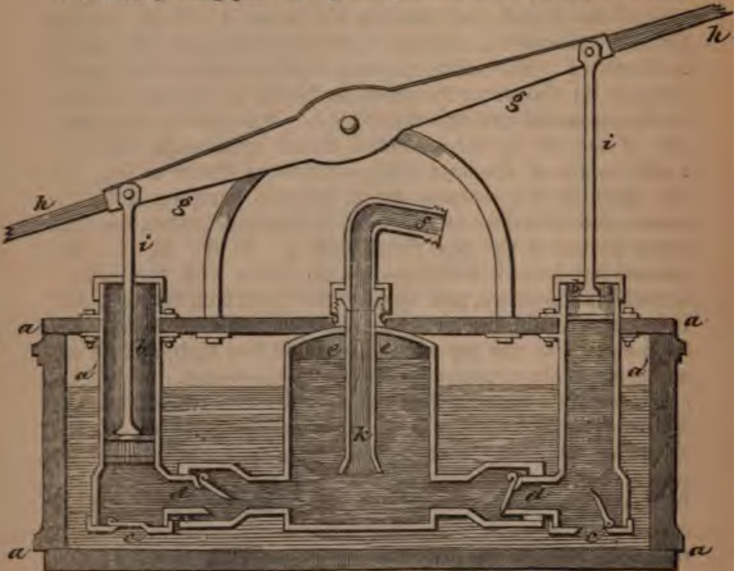


Fig. 116.—Fire Engine.

resisted by the air at the top of the receiver, and thus seeking an outlet, rushes with impetuosity through the pipe *k*, and is directed to the proper object by the hose screwed on at *f*. The little portable and useful engines used in gardens are constructed on a similar principle.

The great defect of forcing pumps where air-vessels are used is the absorption of the air by the issuing water, so that in process of time nearly all the air in the receiver is passed out by the water, which consequently becomes intermittent. To obviate this defect, an arrangement in the following manner is made. The pump-barrel is at *a a* (fig. 117), the piston at *b*, and the piston-rod at *c*; *d d* is the pipe communicating with the water to be pumped up. On the piston being raised the

valve *e* opens, and a vacuum being produced beneath the piston, the water rises from the well; while this part of the operation is being performed, the valve *g* opens, and the water above the piston-rod is lifted up and forced out at *g* into the delivery-pipe *i i*. On the piston-rod being depressed the valves *e* and *g* close, and a vacuum being created above it, the valve *f* opens and admits the water from *a* to that part of the barrel above the piston: at the same time the valve *h* opens, and as the piston descends the water beneath is forced through *h* into the delivery-pipe *i i*. It will thus be plain that there must be a continual stream of water forced through the delivery-pipe, as both the down and up stroke act in giving permanence to that effect.

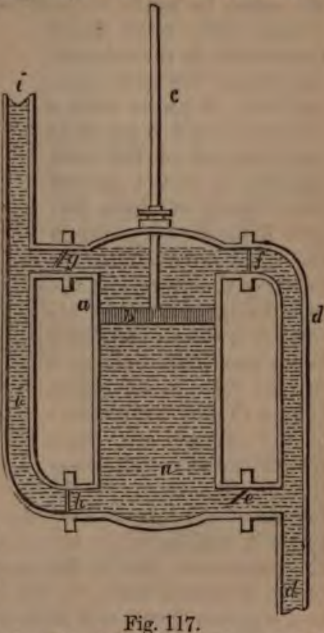


Fig. 117.

The force-pump is employed frequently to supply the boiler of a steam-engine with water, that the pressure of the steam in the boiler may be overcome. Hot water may be pumped in; but should the pump be applied to raise water which has more than 150 degrees of heat, on the piston being lifted up the expected vacuum will be found filled with steam given off by the water, and the pump therefore labours fruitlessly.

Syringes.

The common *water-syringe* consists of a wide tube ending in a nozzle, and at the other end a handle attached to a light piston. Dipping the nozzle in water, this is drawn up by drawing the handle, and may afterwards be squirted out by depressing it.

There are two descriptions of *air-syringes*; one for forcing

more air into a vessel, called a *condensing syringe*; and another for drawing air out of a vessel, which is named an *exhausting syringe*. Both consist of a tube closed at one end, excepting an orifice to which a valve is affixed. In the condensing syringe this valve opens downward; in the exhausting syringe the valve opens upward. A piston with a handle and rod is put in at the other end of the tube, and can be moved up and down; each of these pistons has valves opening in the same direction as the valves of the tubes. If the exhausting syringe be affixed to a vessel, the piston being down, on drawing it up, the valve in the piston is kept shut by the pressure of the external air, while the air in the vessel, pressing on the valve at the bottom of the tube at the rate of 15 lbs. on the square inch, raises it, and the air in the vessel passes between the valve in the piston and that in the bottom of the tube. When the piston is pressed down, the valve at the bottom closes and that in the piston opens, and thus the operation is continued until the vessel be pumped free from air (fig. 118).

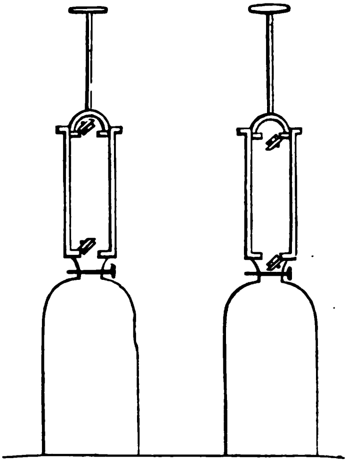


Fig. 118.

In the condensing syringe the valves are hung so as to act in a contrary direction: when the piston is pushed down, the pressure of the air in the tube and vessel shuts the valve in the piston, and the air in the tube is forced into the vessel; on drawing up the piston, the pressure of the air within the vessel closes the valve at the bottom of the tube, while the external air opens that of the piston; on pressing the piston down again, the piston-valve closes, and the air in the tube forces the tube-valve open and the air into the vessel. Thus the operation is continued as long as the experimenter has strength to force more air in, or the vessel to bear it.

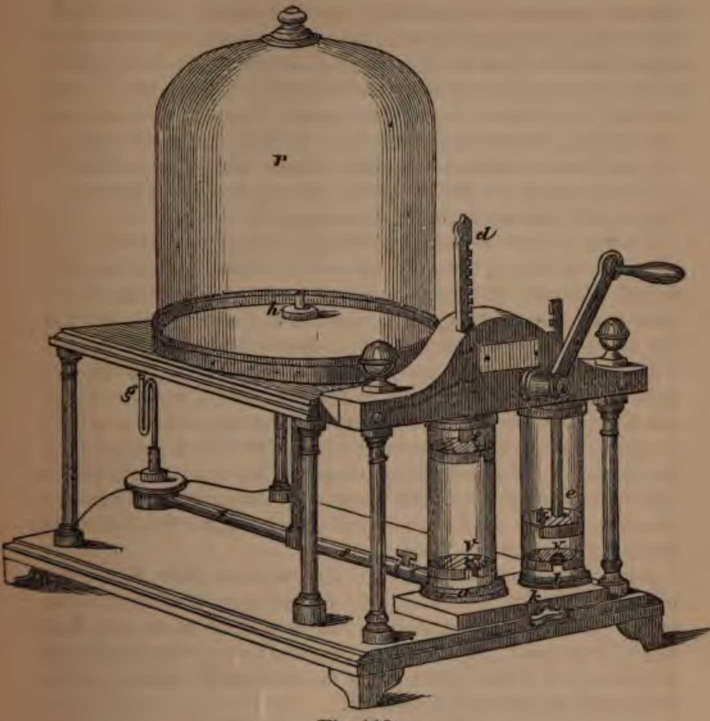


Fig. 119.

The Air-pump.

This instrument is for the purpose of withdrawing the air from any closed vessel. It may be drawn from a bag or bladder; but for general experiments there is a round glass with an arched top *r* (fig. 119), and open at the bottom, called a receiver. This glass is placed with its open part downwards on a flat smooth surface, usually a metal plate, and where it touches the plate it is greased, or adapted to a piece of wet leather to render it perfectly air-tight. In the metal plate is a hole *h*, communicating by a tube *f f* with two strong brass pump-barrels, *a*, *b*. In each barrel is a valve *v v*, opening upwards,

and also valves $e\,e$ in two tightly-fitting pistons: at the top of these pistons is some rack-work d, which works in a little cog-wheel attached to a handle. A half-circular turn being given to the handle, the pinion works the racks up and down. On each of the pistons rising, the air rushes from the receiver into the vacuum created in the barrel. As the pistons alternately descend, the air escapes from the barrels, and thus the handle is worked until all the air under the receiver is drawn away. The double barrels expedite the operation.

In the cylinder or barrel a the piston is represented in the act of ascending when the valve e is closed, and a vacuum would be formed beneath the piston but for the opening of the valve v by the elasticity of the air in the receiver r. In the barrel b the piston is in the act of descending when the valve v is closed and the valve e open, by which all the air in the cylinder is forced out; and in this manner a portion of the air is withdrawn from the receiver r at every stroke of the pump. k is a cock, by turning which air is re-admitted into the receiver, and this thereby loosened; g is a small graduated tube filled with mercury (the pressure gauge), which, from the mercury sinking as the air is exhausted, shows the extent to which exhaustion is carried.

In the working of this useful philosophical instrument, the utility and action of the simple contrivance of a valve must be very striking. As the air rushes out, it gives way and allows it to pass; but as soon as it attempts to enter, it closes, and the more forcibly the air is made to push against it, the closer and tighter does it become.

Many useful experiments are made with the air-pump. The weight of the air may be personally felt by placing the hand on one end of a glass tube which is open at both ends, the other end being placed over the hole of an air-pump; on exhausting the air, the weight of the external air is felt most painfully. If the hand be removed, and a piece of parchment substituted and tightly tied on, it will sink inwards and finally burst with a loud report.

A glass of liquid placed underneath a receiver, on the air being withdrawn will bubble up, from the air contained in it escaping; by this means is seen the amount of air held in many liquids and solids.

A favourite experiment is to place a shrivelled apple under

the receiver, when it assumes all the plumpness and smoothness of fresh ripeness instead of the wrinkles of age; but when again presented to fresh air, the apparent youthfulness is lost, and the appearance consequent on its natural condition returns.

A bladder half-filled with air and tightly tied at the neck, when similarly treated will expand till it bursts. An egg with a prick in the narrow end, under an exhausted receiver, will become empty, from the air contained in the broad end expanding and forcing out all the delicate food encased in the shell.

These facts illustrate *the expansion of air*. The expansibility of air must be very great; for if only one-thousandth part of the quantity contained in the receiver be left, there is still spring enough to move the valve of the pump.

As the valves in air-pumps are apt to get out of repair, it is a desideratum to have an apparatus without them. Mr. Ritchie invented one to act without valves, which is therefore so far simplified in construction. The diagram is merely illustrative of its principle, not of the arrangement of the parts, which may be made to suit convenience. A barrel *a a* (fig. 120) is provided with a piston *b b*, the rod of which works through an air-tight stuffing-box at *g*; the receiver *d* standing on a table *f* is connected to the barrel by a pipe *e e*. There is a small hole in the cover at *c*, similar to the vent of a flute. Suppose the piston now seen at the bottom of the barrel beneath the aperture of the pipe *e e* be raised, the air above it is forced through the aperture *c*; the finger being put on *c*, by which it is closed and becomes

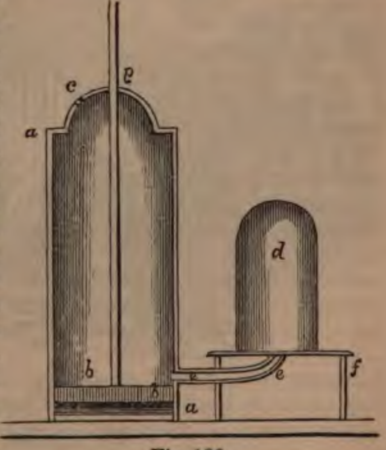


Fig. 120.

perfectly air-tight, the piston is pressed down, and forms a vacuum above it: immediately on the piston passing the aperture

of the pipe *e e*, the air from the receiver *d* rushes into the barrel to fill up the vacuum. The piston is then raised, and the air passes through *c*, the operation being repeated till the requisite degree of extension is obtained in the receiver *d*.

This principle of the air-pump has been long applied to manufacturing purposes. Watt adopted it in his steam-engine; and in paper-making, sugar-making, and tanning of leather, and numerous other purposes, it has been successfully used. A machine is fitted up similar to an air-pump, having a tube connected with the syringe and a receiver; but in this case the receiver is firmly fastened down by a cross-piece of some material affixed to pillars.

Fig. 121.

The Siphon.

Every one must have observed, in passing along the streets when the great waggons of the distillers are standing opposite

some spirit-shop, this instrument in action emptying the huge casks (fig. 121).

The siphon is a bent tube *b b* (fig. 122) having two legs of unequal length. When used, the shorter leg is inserted into the bung-hole of a cask or other vessel *a a* from which it is desired to draw off the liquid it contains. The tap *c* is first closed, then the mouth of a person is applied to a small pipe *d d* to create a vacuum, or the siphon is previously filled with liquid. The tube *d d* is not essential to the instrument. From the pressure of the atmospheric air on the surface of the liquid it rushes into the siphon, when the tap *e* of the small pipe is closed and that of the larger one *c* opened; the liquid then flows out as long as the short leg is beneath the surface of the liquid, and the extremity of the long leg is at a lower level. By this contrivance, the vessel to be emptied need not be moved, and any sediment, as at *m m*, remains undisturbed. The weight of the liquid in the longer leg falling from its own gravity would leave a vacuum, did not the pressure of the air in the cask or vessel force the liquid up and supply its place.

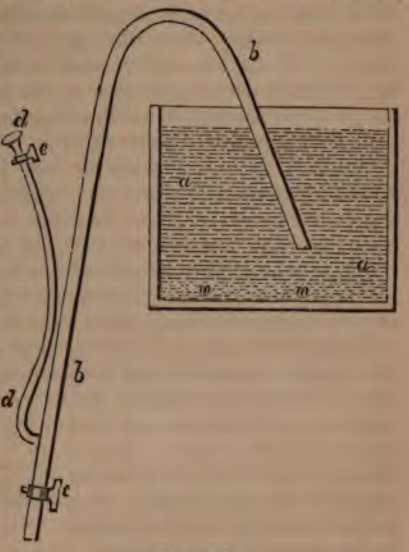


Fig. 122.

Sometimes siphons are formed on a very large scale for supplying towns with water, or draining ponds or lakes; but the same law exists with regard to them as the pump; that is, they must not rise above thirty-two feet from the surface of the water, for beyond this point the fluid will not flow.

If a bent tube have two legs of equal length, and be then

filled with water and one leg turned downwards into water, the fluid will not run off as in the siphon described above; but if a small inclination be given, one leg in effect is made longer than the other, and the water will flow off as long as there is any water remaining in the vessel. The reason of the water not flowing when the legs are equally long, is that the pressure of the atmosphere acts equally on both ends of the tube; but by shortening one of the legs the balance is destroyed, and the weight of the longest column of water preponderating pulls the other after it.

We know that if a chain or rope is hanging over a high beam, when the two parts are equal it is at rest; but make one longer than the other, then the long one drags the other after it. The contents of a siphon may be compared to a chain of water, the weight of the longer leg dragging the accumulated water off in a stream or chain, the pressure of the air preventing this liquid chain from breaking.

Mitscherlich contrived a very neat little siphon (fig. 123) for operative chemists, that they might draw off a liquid from above downwards without disturbing any sediment *d* that might be in the vessel. It consists of a bent tube *a b c*, having legs of unequal length; that which is the shortest, and the one to be inserted in the liquid, is bent upward at the end *c*, so that the liquid flows into it from above, and does not in the slightest affect that below. The finger is placed on *b*, when the instrument is intended to be used, and the air being drawn out by sucking at *e*, the liquor flows in, and the finger being removed, it runs out at *b*.

Fig. 123.

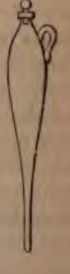


Fig. 124.

The *dipping siphon* (fig. 124) bears but little resemblance to the true siphon. Its principle is that water which can only quit a vessel by a small hole, a hole too small to allow air to pass in to fill up the vacuum made, is retained in that vessel by the pressure of the atmosphere. It is used where the contents of barrels or other vessels have to be tasted, and there

is no preparation for drawing off the liquid; it is a small narrow tubular vessel open at both ends, but contracted at the extremity and neck. On dipping it into the barrel or vessel, the liquid enters and fills it; the thumb is then placed on the hole at the top of the neck, and being drawn out, none of the liquor escapes until the thumb is removed: upon doing so, a glass or other vessel can be filled.

We cannot leave this subject without noticing the pleasing toy called Tantalus's cup. The poor fellow stands up to his neck in water, as described in the fable, and whenever the water is brought to the level of his chin, and he is about to quench his unbearable thirst, the water vanishes. This is accomplished by the figure having within it a concealed siphon. The longer leg passes through the bottom of the cup in which the figure is placed, and the water is made to stand not quite so high as the bend of the siphon; therefore upon raising the water to the lips, it is over the bend of the tube, and runs out until the vessel is empty. On the same principle a conjuring trick is shown by having a siphon concealed in the handle of a drinking vessel, and upon asking a person to partake of the contents, when in the act of placing it to the mouth, it recedes, and disappointment ensues.

In decanting a bottle of wine, the air enters at one side of the neck, and thus allows the wine to pass out. If a tap be driven into a full barrel, the liquor will only dribble out; but if a small hole be made in the part uppermost, then the pressure of the admitted air forces it freely out of the tap. A large hole, on the same principle as the bottle, permits air to find its way in, and then a barrel may be speedily emptied without a vent-hole.

The Barometer.

The fact related in a preceding article, that 34 feet of water balance the pressure of the atmosphere, was discovered by the celebrated Galileo. Some pump-makers, employed by the Duke of Tuscany, finding they could not raise water above 30 feet, in their dilemma applied for assistance to the philosopher, who proved to them that the law of nature did not permit of water rising above a certain height in a cylinder from which the air had been exhausted. Not only on the discovery of the pressure of the atmosphere, but on other philosophical subjects

did Galileo contend against the prejudices and ignorance of the time in which he lived. Evangelista Torricelli, a young man residing at Rome, watched with deep interest the many important truths elucidated by Galileo; and writing two tracts, one on the motion of fluids, and the other on mechanics, he received from the aged philosopher an invitation to come to Florence. Shortly afterwards Galileo died, and Torricelli, at the age of thirty-nine, succeeded to the chair of mathematics in the famous academy of that city. Torricelli, wishing to establish the truth of the pressure of the atmosphere, used, as more convenient for experiment, mercury instead of water, making an allowance for the increase of weight, which is about thirteen times that of water.

He took a glass tube, one end of which was sealed, and having filled it with mercury, he placed the open end in a vessel *a b* (fig. 125) containing the same material. On doing this, he noticed that the mercury escaped from the glass tube until it stood at *s*, a height a little more than 29 inches above the vessel of mercury in which the open end of the tube was placed. Thus, then, if the pressure of the atmosphere supported mercury to a little over 29 inches, by multiplying that height by $13\frac{1}{2}$ (mercury being so many times as heavy as water), he obtained the result stated by Galileo of about 32 feet (at Florence). Then to prove that atmospheric pressure varied under different circumstances, he made the same experiment on the tops of high buildings and the summits of mountains. The result to the world was the great discovery of the barometer. The variation of the mercury on coming storms and hot weather was remarked, and its important application to the wants of man on sea or land rendered apparent. To the shepherd in saving his flocks, to the farmer in storing his hay or corn, to the sailor in preserving his ship and crew, the barometer is invaluable; for often when all is serene and sunshine, without a speck in the vault of heaven, the faithful monitor will give note of coming danger.

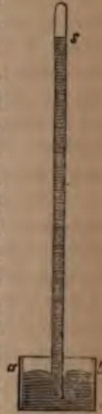


Fig. 125.

Three vessels were sailing in the Chinese seas in 1847 in very calm weather. The first vessel suddenly hauled in every sail. The singularity of this act, apparently without any

reason for so doing, struck the mariners on board the second ship with astonishment, and the mate and captain consulted together as to this strange conduct, when it occurred to the former to hasten to the cabin and look at the barometer; and in his fright, he shouted out that it had suddenly sunk an inch. Every hand was instantly at work, and in a few minutes the vessel was under bare poles. They now turned their attention to the last vessel, and on looking, saw every officer with his telescope attempting to define the cause for such a remarkable and rapid manœuvre. Seeing they did not follow their example, the captain signalled to them the impending danger, and at once they began to take in sail; but it was too late, a terrific typhoon swept over the ocean—the azure sea became a mass of white foam—the vessels were whirled about like chaff. As soon as possible they looked for their companions; the first was safe, the other had found a watery grave. Torricelli's contemporaries scoffingly demanded of him the *practical use* of this new instrument. The sailors who witnessed this scene could have given a more satisfactory reply to these questioners than the inventor himself.

Fig. 126.

The barometer (which means a *weight measure*) consists of a narrow glass tube, about 34 inches long, closed at the top, having a small bulb of mercury at the lower end; this is placed upright in a frame, and from 5 to 6 inches exposed to view, on which part there are figures indicating the number of inches from the mercury at the bottom of the tube, and the words fair, change, wind, rain, stormy, &c. (fig. 126).

Others are termed wheel-barometers; these have a bent tube C K B (fig. 127) to hold the mercury, on the top of which is a small float E, having a silken thread A attached, passing over a pulley Q, and balanced by a little plummet R. On the rise or fall of the mercury, the thread turns a small pointer H, which indicates the

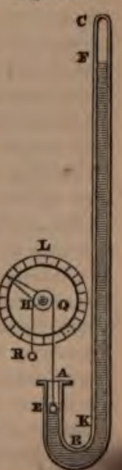


Fig. 127.

various changes, as they are marked on a dial L, similar to the face of a clock.

In England, the ordinary range of the mercury is from 29 to 30 inches, and its greatest 3 inches; in Russia, $3\frac{1}{2}$ inches. Near the tropics there is little or no variation: at Jamaica seldom more than three-tenths of an inch; and at Naples about 1 inch.

For minute observation, there is a little graduated index called a vernier, affixed, which shows the fluctuation of the mercury to the hundredth part of an inch.

The barometer, as a *weather-glass*, cannot be said to give an invariable indication; it merely shows that a change is taking place from the former condition of the atmosphere. It measures the *weight of the air*, and becomes a weather-glass only by reason of the observed fact that the column of atmosphere is heavier in fine, lighter in foul weather. When the mercury rises, fair weather may be expected, and when it falls, rain, snow, and storms; when it falls very low, it presages great winds, though not necessarily rain. In summer, when the mercury descends, thunder may be expected; in winter, when it rises, frost; a fall during frost indicates a thaw, and a rise, snow. If the change in weather follows closely upon that of the mercury, such change will be of short duration. When mercury falls quickly, it indicates wind; and if it fall half an inch in an hour in London, and immediately change its direction, there may be expected a wind with a velocity of nearly 60 miles an hour. If there be a sudden fall of the mercury, and no particular immediate change, by noting the direction of the wind some hours afterwards, the situation of the storm that occurred may be known; and if the time from the falling of the mercury to the changing of the wind be noted, the exact distance of the storm may be calculated. For the atmosphere at that place having become rarefied, the air moves rapidly from all parts to fill up the partial vacuum, as air is drawn to a fire-place by the heat. This was beautifully illustrated in the Great Exhibition, where the direction of the wind in all the principal towns was shown by the position of little arrows, the information being daily transmitted by electric telegraph. The theory stated above was carefully watched by Mr. Holmes; and he became perfectly satisfied, by demonstration, of its truth. The same gentleman considers that every storm has a similar

one at its antipode; that storms being excited by electricity, it is possible that one may exist at a positive and one at a negative point. The observations, as yet, are too few to establish the fact; but as far as at present known, they are corroborative.

Barometers are further employed for measuring heights. At the level of the sea the mercury stands, say at 29 inches and five-tenths; at a height of 500 feet, it is found to have sunk half an inch. At 3½ miles it is 15 inches, or nearly one-half; at the height of 4 miles only 12 inches high. This proves that one-half of our atmosphere is within 3½ miles of the earth's surface.

In 1844 an *aneroid barometer* was patented, in which, instead of depending on the pressure of the atmosphere on mercury, the variations were pointed out by the pressure of the air on laminæ or diaphragms, consisting of thin sheets of metal, glass, caoutchouc, or other elastic substance; but generally a thin piece of copper-sheet corrugated circularly, so as to be sensible of the slightest pressure. A dial-plate with index pointers is placed over the diaphragm. A brass box, from which the air is extracted, is covered over by this elastic substance, supported from the pressure of the air by a number of delicate spiral springs fixed to the bottom. When the atmosphere becomes heavy, the springs sink, and move the index hand; and when light, the springs become more lengthened, which change is also indicated. This new barometer has not been sufficiently tested by scientific men to justify a decided opinion of its merits; it certainly does not possess the simplicity of the mercurial barometer, which in principle is a common lever. Nevertheless it shows the wonderful elasticity of the atmosphere. The atmosphere is acted upon by gravity, and its weight is greatest at the surface of the earth, and less the higher we ascend. The invention of the barometer decided its exact weight. To prove that this weight is the cause of the mercury standing in the tube of the barometer, it is sufficient to place the tube in a basin of mercury, under the receiver of an air-

Fig. 128.

pump, when at every turn of the handle the mercury sinks; and if all the air be removed from the surface of the mercury, the height of that in the tube and basin will be the same. When the air is allowed to enter, the mercury rises in the tube to its usual height. The pressure of the atmosphere is thereby proved to be equal to a column of mercury 30 inches high; now if it be calculated at 1 inch square at its base, that will be 30 cubic inches of mercury; and as a cubic inch of mercury weighs 7·85 ounces, this multiplied by 30 is equal to 235·5 ounces, or 14·9 pounds. We commonly say, therefore, that the atmosphere at the earth's surface presses on all things it touches with a weight of 15 lb. on every square inch. Hence the weight of the atmosphere is the same as if the whole globe were covered with a skin of mercury 30 inches thick. This weight is equal to that of a solid globe of lead 60 miles in diameter, which if we had to move, we should hardly use with respect to it the flippant expression "as light as air."

The following manual of the barometer has been compiled by Rear Admiral FitzRoy:—

A rapid rise of the barometer indicates unsettled weather; a slow movement the contrary; as likewise a steady barometer, which, when continued, and with dryness, foretells very fine weather.

A rapid and considerable fall is a sign of stormy weather and rain (or snow). Alternate rising and sinking indicates unsettled and threatening weather.

The greatest depressions of the barometer are with gales from S.E., S., or S.W.; the greatest elevations, with wind from N.W., N., or N.E., or with calm. Though the barometer generally falls with a southerly and rises with a northerly wind, the contrary sometimes occurs; in which cases the southerly wind is usually dry with fine weather, or the northerly wind is violent and accompanied by rain, snow, or hail; perhaps with lightning.

When the barometer sinks considerably, much wind, rain, (perhaps with hail) or snow will follow; with or without lightning. The wind will be from the northward, if the thermometer is low (for the season); from the southward, if the thermometer is high. Occasionally a low glass is followed or attended by lightning only, while a storm is beyond the horizon.

A sudden fall of the barometer, with a westerly wind, is sometimes followed by a violent storm from N.W., or N., or N.E.

If a gale sets in from E. or S.E., and the wind veers by the S., the barometer will continue falling until the wind is near a marked change, when a lull *may* occur; after which the gale will soon be renewed, perhaps suddenly and violently, and the veering of the wind towards the N.W., N., or N.E. will be indicated by a rising of the barometer with a fall of the thermometer.

Three causes (at least) appear to affect the barometer:—

1. The direction of the wind—the north-east wind tending to raise it most; the south-west to lower it the most, and wind from points of the compass between them proportionally as they are nearer one or the other extreme point. N.E. and S.W. may therefore be called the wind's extreme bearings (rather than poles). The range or difference of height shown due to change of direction only, from one of these bearings to the other (supposing strength or force and moisture to remain the same), amounts in these latitudes to about half an inch (as read off).

2. The amount—taken by itself—of vapour, moisture, wet, rain, or snow in the wind, or current of air (direction and strength of wind remaining the same), seems to cause a change amounting in an extreme case to about half an inch.

3. The strength or force alone of wind, from any quarter (moisture and direction being unchanged), is preceded or foretold by a fall or rise, according as the strength will be greater or less, ranging in an extreme case to more than 2 inches.

Hence, supposing three causes to act together—in extreme cases—the height would vary from near 31 inches (30·9) to about 27 inches (27·0), which has happened, though rarely (and even in tropical latitudes). In general, the three causes act much less strongly, and are less in accord; so that ordinary varieties of weather occur much more frequently than extreme changes.

Another general rule requires attention, which is, that the wind usually appears to veer, shift, or go round with the sun (right-handed, or from left to right), and that, when it does not do so, or backs, more wind or bad weather may be expected instead of improvement.

It is not by any means intended to discourage attention to what is usually called "weather wisdom." On the contrary, every prudent person will combine observation of the elements with such indications as he may obtain from instruments, and will find that the more accurately the two sources of foreknowledge are compared and combined, the more satisfactory their results will prove.

A barometer begins to rise considerably before the conclusion of a gale, sometimes even at its commencement. Although it falls lowest before high winds, it frequently sinks very much before heavy rain. The barometer falls, but not always, on the approach of thunder and lightning. Before and during the earlier part of settled weather it usually stands high and is stationary, the air being dry.

Instances of fine weather, with a low glass, occur, however, rarely; but they are always preludes to a duration of wind or rain, if not both.

After very warm and calm weather, a storm or squall, with rain, may follow; likewise at any time when the atmosphere is heated much above the usual temperature of the season.

Allowance should invariably be made for the previous state of the glasses during some days, as well as some hours, because their indications may be affected by distant causes, or by changes close at hand. Some of these changes may occur at a greater or less distance, influencing neighbouring regions, but not visible to each observer whose barometer feels their effect.

There may be heavy rains or violent winds beyond the horizon, and the view of an observer, by which his instruments may be affected considerably, though no particular change of weather occurs in his immediate locality.

It may be repeated that the longer a change of wind or weather is foretold before it takes place, the longer the presaged weather will last; and conversely, the shorter the warning, the less time, whatever causes the warning, whether wind or a fall of rain or snow, will continue.

Sometimes severe weather from the southward, not lasting long, may cause no great fall, because followed by a duration of wind from the northward, and at times the barometer may fall with northerly winds and fine weather, apparently against these rules, because a continuance of southerly wind is about

to follow. By such changes as these one may be misled, and calamity may be the consequence, if not duly forewarned.

A few of the more marked signs of weather, useful alike to seaman, farmer, and gardener, are the following:—

Whether clear or cloudy, a rosy sky at sunset presages fine weather; a red sky in the morning bad weather, or much wind (perhaps rain); a grey sky in the morning, fine weather; a high dawn, wind; a low dawn, fair weather.

Soft-looking or delicate clouds foretell fine weather, with moderate or light breezes; hard-edged, oily-looking clouds, wind. A dark, gloomy, blue sky is windy; but a light, bright blue sky indicates fine weather. Generally the softer clouds look, the less wind (but perhaps more rain) may be expected; and the harder, more "greasy," rolled, tufted, or ragged, the stronger the coming wind will prove. Also, a bright yellow sky at sunset presages wind; a pale yellow, wet—and thus by the prevalence of red, yellow, or grey tints, the coming weather may be foretold very nearly; indeed, if aided by instruments, almost exactly.

Small inky-looking clouds foretell rain; light scud clouds driving across heavy masses show wind and rain, but, if alone, may indicate wind only.

High upper clouds crossing the sun, moon, or stars in a direction different from that of the lower clouds, or the wind then felt below, foretell a change of wind.

After fine clear weather the first signs in the sky of a coming change are usually light streaks, curls, wisps, or mottled patches of white distant cloud, which increase, and are followed by an overcasting of murky vapour that grows into cloudiness. This appearance, more or less oily or watery, as wind or rain will prevail, is an infallible sign.

Usually the higher and more distant such clouds seem to be, the more gradual, but general, the coming change of weather will prove.

Light, delicate, quiet tints or colours, with soft, undefined forms of clouds, indicate and accompany fine weather; but gaudy or unusual hues, with hard, definitely outlined clouds, foretell rain, and probably strong wind.

Misty clouds forming or hanging on heights show wind and rain coming, if they remain, increase or descend. If they rise or disperse, the weather will improve or become fine.

When sea-birds fly out early, and far to seaward, moderate wind and fair weather may be expected; when they hang about the land or over it, sometimes flying inland, expect a strong wind with stormy weather. As many creatures besides birds are affected by the approach of rain or wind, such indications should not be slighted by an observer who wishes to foresee weather.

There are other signs of a coming change in the weather known less generally than may be desirable, and, therefore, worth notice—such as when birds of long flight, rooks, swallows, or others, hang about home, and fly up and down or low, rain or wind may be expected. Also when animals seek sheltered places, instead of spreading over their usual range; when pigs carry straw to their sties; when smoke from chimneys does not ascend readily (or straight upwards during calm), an unfavourable change is probable.

Dew is an indication of fine weather; so is fog. Neither of these two formations occurs under an overcast sky, or when there is much wind. One sees fog occasionally rolled away, as it were, by wind; but seldom or never formed while it is blowing.

Remarkable clearness of atmosphere near the horizon, distant objects, such as hills, unusually visible, or raised (by refraction), and what is called "a good hearing day," may be mentioned among the signs of wet, if not wind, to be expected.

More than usual twinkling of the stars, indistinctness or apparent multiplication of the moon's horns, haloes, "wind dogs," and the rainbow, are more or less significant of increasing wind, if not approaching rain, with or without wind.

Near land, in sheltered harbours, in valleys, or over low ground, there is usually a marked diminution of wind during part of the night, and a dispersion of clouds. At such times an eye on an overlooking height may see an extended body of vapour below (rendered visible by the cooling of night) which seems to check the wind.

Lastly, the dryness or dampness of the air, and its temperature (for the season), should always be considered, with other indications of change, or continuance of wind and weather.

On the Nature of Winds.

The rising of smoke in chimneys is caused by the heated

and rarefied air floating upwards through the more dense mass till it arrives at a state of the atmosphere equal to itself in density, carrying with it the small particles of coal not consumed; these attain a particular height, and then fall again, as is discoverable in all towns by the dirt covering the windows, and the dust lying on furniture. On the same principle, when the air at the earth's surface becomes heated, it rises, and the colder and more dense air rushes into its place, an action which constitutes what is termed *wind*. The sun is continually heating the air at the equator, and following the universal law it rises, creating a current of wind from the northern and southern regions; but as the earth is whirling eastward, it makes the one to blow north-east, and the other south-east. These are the trade-winds. When the sun is on the equator, these winds change as the position of the sun with regard to the earth is altered. The loftier currents of the atmosphere carry the heated air towards the poles, which in its passage becomes cooled. Winds may be termed strong currents of air.

In several parts of the eastern and southern oceans, the winds blow at particular periods in one direction, and are called *periodical*; they also are dependent on the sun; from the end of March to the end of September the winds set in from the south-west, and for the remainder of the year, when the sun is south of the equator, the wind blows from the north-east. These *monsoons* or shifting winds are the ends, as it were, of the influence of the trade-winds in southern latitudes, nearly corresponding to our equinoctial gales in the northern extremities. During the changes, occur those variable winds and terrible storms so dreaded by our hardy navigators.

Between the tropics, on the greater part of the coasts the wind blows towards the sea at night and towards the shore in the daytime. How wonderful is this economy of nature! During the intense heat of the day the air over the heated land becomes rarefied and rises, while the cool air from the ocean flows in to supply its place; on the other hand, during the night the air in contact with the mountains and hills, being cooler even than that overhanging the sea, flows down into the valleys; thus is a healthful equilibrium preserved. These are called *sea and land breezes*. They may be exemplified by putting in the middle of a large dish of cold water

a saucer filled with hot water; the latter supposed to be the land, the former the sea. Take a candle which has just been blown out and hold it over the cold water,—the smoke will be seen to move towards the saucer containing the hot water. Again, fill the dish with hot water and the saucer with cold, then hold the extinguished candle over the saucer, and the smoke will move to the dish of hot water.

In this country exist what are called *variable winds*; changing often in the most rapid manner, the clouds passing in different directions to the breeze felt at the earth's surface. Usually a south and west wind, which blows from the Atlantic, brings warmth and moisture; a north and east wind, cold and dryness. In Western Europe storms come generally from the south-west, and arise from the struggle of a powerful south-west current with that setting from the north-east: the south-west wind also contains most moisture. The force of storms is accounted for by the vast swiftness of their progress.

Much attention has been given by scientific men to the subject, and the following are the results they have arrived at:—

THE PREVAILING WINDS AT LONDON.

Winds.	Days.	Winds.	Days.
South-west	112	South-east	32
North-east	58	East	26
North-west	50	South	18
West	53	North	16

The south-west wind blows more upon an average in each month of the year than any other, particularly in July and August; the north-east prevails during January, March, April, May, and June, and is most unfrequent in February, July, September, and December; the north-west occurs more frequently from November to March, and less so in September and October, than in any other months.

Average of seven years, by Dr. Meek, near Glasgow:—

Winds.	Days.	Winds.	Days.
South-west	174	North-east	104
North-west	40	South-east	47

In Ireland the prevailing winds are the west and south-west. If the wind veers about much, rain will ensue; if in changing it follows the course of the sun, it brings fair weather; the contrary, foul.

CAPTAIN BEAUFORT'S SCALE.

	Hourly velocity.		Hourly velocity.
Light air . .	0·1 mile.	Moderate gale . .	30 miles.
Light breeze . .	5 miles.	Fresh gale . . .	45
Gentle breeze . .	10	Strong gale . . .	50
Moderate breeze .	15	Heavy gale . . .	70
Fresh breeze . .	20	Storm	80
Strong breeze . .	25	Hurricane . . .	100, &c.

TABLE OF THE FORCE OF WIND.

The following Table may be considered to express the relation between the velocity and force of wind:—

Velocity of the wind. Miles in an hour.	Feet in a second.	Perpendicular force on one foot area in pounds avoirdupois.	Common terms used of the force of wind.
1	1·47	·005	Hardly perceptible.
2	2·93	·020	Just perceptible.
3	4·40	·044	
4	5·87	·079	Gentle pleasant wind.
5	7·33	·123	
10	14·67	·429	Pleasant brisk gale.
15	22·00	1·107	
20	29·34	1·968	Very brisk.
25	36·67	3·075	
30	44·01	4·429	High wind.
35	51·34	6·027	
40	58·68	7·873	Very high wind.
45	66·01	9·963	
50	73·35	12·300	Storm or tempest.
60	88·02	17·715	Great storm.
80	117·36	31·490	A hurricane.
100	146·70	49·200	A hurricane that tears up trees, carries buildings before it, &c.

Mode of Collecting Gases.

The principle of the lighter fluid floating up through a heavier one is exemplified in that useful apparatus found in the laboratory of the chemist, and exhibited in popular lectures on the science of chemistry—the *pneumatic trough.*

The material from which it is desirable to evolve gas is placed in a retort *a* (fig. 129) or other convenient apparatus, and sometimes heated by a spirit-lamp *b* or fire. The gas flows along the pipe-neck of the retort, the end of which is placed under water, and leaving the pipe, floats up through

the water, enters the receiver c, displaces the water in it, and

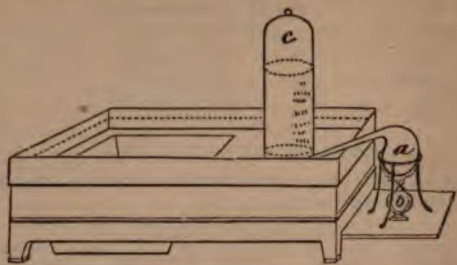


Fig. 129.

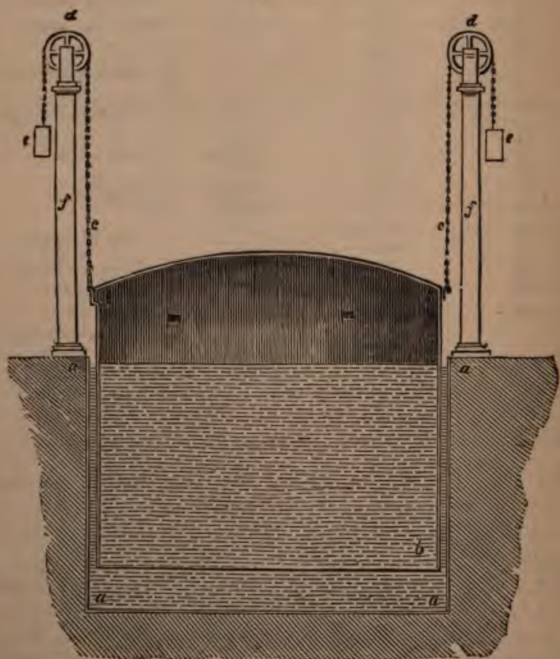


Fig. 130.

is thus collected for the purposes required by the experimenter. When it is desired to preserve the gas, or move it to a distance conveniently, a bladder should be screwed on to the top of the receiver, which being gradually sunk in water, the gas is pushed upwards into the bladder.

On a large scale, the operation we have just described is carried on in those gas-works which supply towns—the vessel which holds the gas being called a gasometer. This consists of a large cylindrical vessel *b b b* (fig. 130), made of sheet-iron and perfectly air-tight, suspended mouth downwards by chains *c c*, pulleys *d d*, and balance-weights *e e*, in a tank of water *a a*. The gas flows in through the water by means of pipes, and raises up the receiver. Other pipes are placed to conduct the gas to its destination, which come out above the water, and by certain contrivances a steady pressure is kept up to force the gas out, thus giving a continuous even light to all the consumers. *f f* are the pillars for supporting the pulleys; the gas occupies the top, *m m*, of the gasometer as it rises.

The Diving Bell.

The observation, that on thrusting a glass with its mouth downwards in water, the air resisted the liquid so as only to allow it to rise a little height in the glass, gave rise to that valuable modern invention the *Diving Bell*. By means of this invention much treasure has been rescued from the bottom of the ocean, the foundations of lighthouses have been laid, the walls of piers constructed under water, and the foundations of bridges built and repaired. These bells, although sometimes square, are generally in the form denoted by their name. They are either made of heavy material, or have appliances to cause them to sink. When lowered from the attendant ship or barge laden with workmen, the air becomes compressed, and if sunk to a depth of 34 feet, the air in it is compressed to one-half, or to a double atmosphere. This would allow of the vessel being half-filled with water, while the air would be so condensed that the men would inhale at each breath twice as much as they were accustomed to do on land; therefore, not only to ease the pressure, which is according to the depth the bell is in the water, but also to give vitality to the air, a pipe is connected with it, through which fresh air is forced down to

the men by means of a pump; while at the top of the bell is a cock by which the air that has been breathed is allowed to escape. When it is necessary to leave the bell to travel a short distance, the man having to do so puts on a helmet, and has a pipe leading to it from the bell: should the ground in his exploring expedition be so uneven that he either rises above or below the level of the air in the bell, he at once feels it; when above, the air rushes to him, and becomes so compressed that he with difficulty breathes; and if below, the sluggish supply renders exertion necessary. Still, such is the present excellence of the arrangements for prosecuting submarine labour, that it is now undertaken without more than the ordinary danger attendant on manual operations, and adopted as a common branch of industry. On first going down, a painful sensation is experienced in the ears, which is relieved by resorting to the movement of *swallowing*.

The situation of the diving bell at the depth of 34 feet presents this difficulty to be overcome—the water presses on the air in it with a force of 15 lb. per inch; the power of the force-pump to overcome this resistance, by which the undersea toiler is enabled to pursue his avocations with bearable comfort, must be extraordinary.

Aëronautics.

A man of a philosophical mind, observing some little boys amusing themselves in mixing soap and water, and blowing bubbles through a pipe, and noting that if in this childish game the operation were performed with cold water the tiny globes speedily fell to the ground, and that the hotter the water the more quickly did they soar aloft, is said to have conceived the first idea of an air-balloon.

The first balloons were filled with air heated by a fire kept burning underneath the mouth of the silken bag: the idea being that, by burning straw and other combustibles, a cloud was being formed, caught, and held, so that a man might swing from it and take an aërial journey. When announced as successful, they were the wonder of the age; the world rang with the great discovery, miracles were predicted as capable of being achieved by a flight into the ethereal ocean, while, as is often the case in scientific researches, the impiety of the act was

denounced, and stated to be deserving the vengeance of the Almighty.

The hot-air balloons were succeeded by those filled with hydrogen gas; but upon the carburetted hydrogen used for the purpose of lighting towns being extensively manufactured, the aëronauts found it more advantageous to increase the size of their silken varnished bags, and fill them with common coal-gas, than have them smaller, and filled by the lighter gas of pure hydrogen.

It is found that a balloon when filled with gas is only the eighth of the weight of the surrounding atmosphere; thus if the weight of the quantity of cubic feet of common air necessary to fill a balloon were 1600 lbs., the same quantity of gas would only weigh 200 lbs.; and if the weight of the apparatus be another 200 lbs., the balloon would lift 1200 lbs. Should the balloon be filled before starting on its aërial voyage, some gas must be allowed to escape, else in its ascent it would expand and burst its silken prison. Not only has this point to be regarded by the managers, but, on being balanced in the air, the machine must be lightened by casting out ballast. On rising beyond a certain height the gas has again to be emitted, as the air becomes more rarefied; thus the more this ascent progresses, the more the power of buoyancy decreases, and a descent at length becomes necessary, requiring skill in effecting it safely.

Man has been gratified in viewing places under an aspect he never could have done but for balloons. The benefit to society from their invention has been comparatively nothing, as no one has hitherto succeeded in guiding them; in the air they are the creatures of every current, and are driven by them whither they list. Gay-Lussac, the celebrated French chemist, ascended to the height of 22,960 feet, upwards of four miles and a quarter, for the purpose of scientific investigation. His principal object was to ascertain if the magnetic influence existing at the earth's surface ceased at a certain elevation, but he could not discover any sensible difference. The air he also found to consist of the same elements as that of the lower strata. Considerable difficulty was found in respiration, and there was a current of upwards of 60 miles an hour.

During the autumn of 1852, four balloon ascents were made by Mr. Welsh, under the guidance of the distinguished aëronaut, Mr. Green. Attention was chiefly directed to the

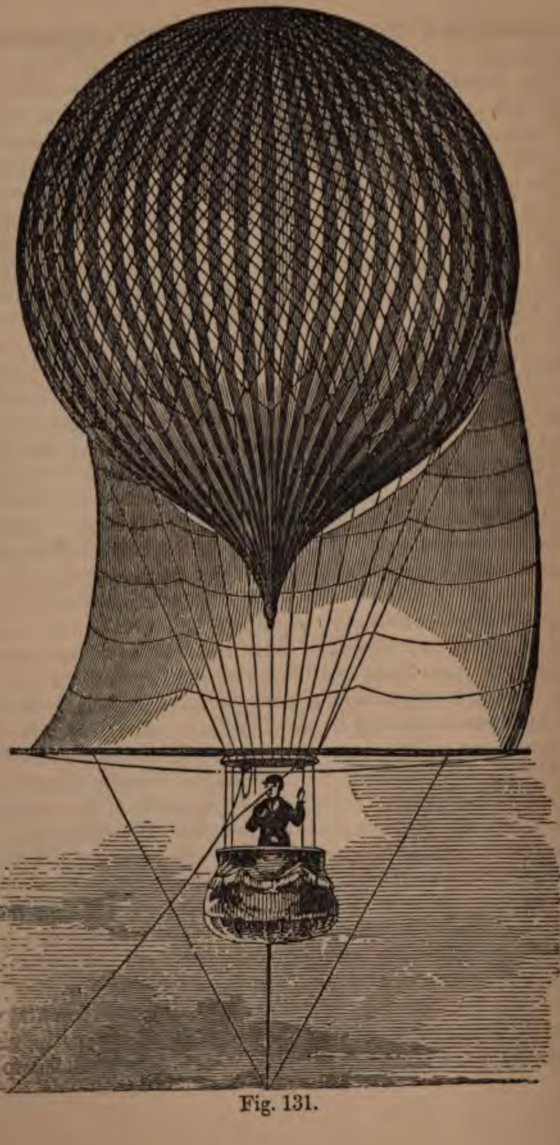


Fig. 131.

determination of the pressure, temperature, and moisture of the air at different altitudes. The decrease of temperature in ascending was very irregular,—being changed even in some cases to an increase; but the mean result gives a decrease of 1° Fahr. for every 348 feet of ascent,—agreeing within 5 or 6 feet with the result obtained by Gay-Lussac. The greatest height attained by Mr. Welsh was 22,940 feet. A repetition of similar observation in ascents made from different points of the earth's surface could scarcely fail to lead to valuable information for the science of meteorology.

The great Nassau balloon, constructed by the veteran aëronaut Green for navigating the aërial ocean, is 64 feet diameter, and when filled holds 80,000 cubic feet of gas. The weight of the silk is 80 lbs.; the greater cable and grappling-iron $3\frac{1}{2}$ cwt., the smaller one $1\frac{1}{2}$ cwt., both of which are taken up in rough weather; the iron ring to which the netting is affixed, and from which the car is suspended, is $3\frac{1}{2}$ cwt.; the entire weight it will carry when loaded to the utmost is 6000 lbs.; if filled with pure hydrogen, it would carry up 40,000 lbs. The large cable is $3\frac{1}{2}$ inches in circumference, and has india-rubber interwoven, that its elasticity may be increased. The greatest number of persons who have ascended in it at one time to enjoy the wonders and participate in the dangers of an aërial voyage, has been eighteen. A barometer, preserved with religious care by this skilful aëronaut, shows the mercury to have been once as low as $7\frac{1}{2}$ inches, which would give the height attained about six miles. He states that all the moisture in the higher regions was in a frozen state, as snow, and not as vapour; and that even on the finest and hottest day, when not a cloud was visible, the balloon was covered by 8 inches of snow.

The difficulty in aërial voyages is that the motion of the balloon cannot be directed by the aëronaut. Fig. 131 is the representation of an attempt once made to overcome this difficulty by the aid of a wind-sail.

One of many attempts to govern these aërial machines was that of Mr. Bell, who made the experiment in the summer of 1850. The machine was of a cylindrical form with conical ends, having its greatest length placed horizontally, or in the direction in which it was to travel. In place of the rope-netting in ordinary use, the patentee used flat silken bands

for the purpose of strengthening the balloon, and affording an attachment to the framework and car. These were placed longitudinally, transversely, and diagonally, round the balloon. Mr. Bell also introduced some improvements in the valve apparatus (fig. 132).

Fig. 132.

The car was formed after the fashion of a canoe or boat. The propellers were on the principle of the screw-propeller. If two were to be used, they were placed one on each side of the car, as in the engraving; if but one, it was to be placed between the car and the balloon, supported in a strong but light framework, to which was attached the steering apparatus or tail. This apparatus was constructed so as to have a hinge and a rotating motion, to obtain the necessary movements of an extended surface or fan, in all respects similar to the tail of a bird, that the guiding or directing of the machine might be under the control of the aëronaut. By the combination of the above motions, the steering apparatus might be moved in any direction, either up or down, laterally, or in any diagonal of these, thus (it was hoped) regulating the direction of the machine in its passage through the air.

This ingenious contrivance failed, and the inventor and his balloon was seen by those who witnessed their trial trip, to drift along with the wind like the aëronauts who preceded him.

Air Engines.

The Air-gun.—By reversing the valves of the air-pump, a condensing syringe is easily made. Some use has been made

of this condensation of air, and it has been substituted for the moving power of bullets in what are called *air-guns,* instead of the gases created by firing gunpowder. In these guns, a condensing syringe fills a cavity having a valve opening inwards, just behind the bullet, which fits the barrel exactly. The air being condensed about forty times as much as the atmosphere, possesses a force of about forty times 15 lb. on the inch, and, upon the trigger being touched, a valve is opened, which, allowing the air to rush out, propels the bullet with this force. The air closes the valve the instant the finger is withdrawn from the trigger. Each discharge is weaker than the one preceding, from the air becoming less dense. Some of these guns have reservoirs of bullets, so that a continuous firing may be maintained as long as the condensed air lasts. The *air-cane* is merely the barrel of the gun with the air previously inserted by means of a condensing syringe.

Pneumatic Pile-drivers.—By the application of a pneumatic principle, a most important improvement has taken place in pile-driving for the foundations of bridges, piers, and other erections in water where the ground consists of mud, sand, earth, gravel, or clay. Instead of having large beams of timber driven in by the force of a weight dropped from a height, the piles are cast-iron cylinders: these are hollow and placed perpendicularly over the spot where they are required to be sunk; the top is made air-tight by fixing on it a cast-iron plate through which a tube is passed connected with a common air-pump. On working the pump a partial vacuum is created in the cast-iron tube, and the earth or other substance at the bottom consequently rises up, while the tube descends into the place thus made for it. On building a bridge across the Shannon, the pneumatic piles were of the enormous size of ten feet diameter; had timber been employed, the piles would have been one foot square. A vacuum inside the tubes equivalent to 13 lbs. on a square inch was created by the air-pump, and the descent of the ponderous tubes into a bed of yellow clay seemed a work of magic. Thus it is that science is ever aiding the industry, the comforts, and the safety of mankind.

An atmospheric pile-driving machine has been patented by Messrs. Clarke and Varley, and was used at Irongate-wharf, London, in sinking the ordinary timber piles. In the common

engine for this purpose, the weight of the rammer is necessarily limited by the amount of manual power that can be brought to bear upon it; and the necessary amount of force in the blow is made up by the height from which the rammer is made to fall. But on the principle we stated under the head of *Momentum*, it is found that a succession of short quick blows with a heavy hammer does the work, not only with much greater speed, but in every way with greater efficiency; also damaging the timber less, and, in fact, forcing it through hard ground which by ordinary methods it would be found impossible to penetrate. By this invention, it would seem that the power of a steam-engine fixed at any convenient spot can, through the medium of atmospheric pressure, be made available at any required distance by the simple application of a vacuum cylinder with its apparatus of self-acting valves, chains, and pulleys, and be attached to a pile-driving machine of the common construction.

The machine was worked by a small high-pressure steam-engine fixed on the shore, to which was attached an air-pump for producing exhaustion. Communication was made with the pile-machine by lengths of small galvanized iron pipes, connected together by flexible joints. Within this was a piston, connected by an iron rod to a chain which passed over a pulley on the top of the frame, the other end of the chain being fixed to a suspended pulley; over this passed a second chain, one end of which was attached to the rammer, and the other passed down to the bottom of the engine, whence again returning upwards, it was fastened to the top of the pile. The action, then, was this: the rammer being down on the head of the pile, and the piston consequently at the top of the air-cylinder, the air in the cylinder was rarefied by the action of the air-pump above, until the external pressure was sufficient to counterbalance the weight of the rammer; this then immediately rose, and as soon as the piston reached the bottom of the cylinder, a motion took place in the self-acting slides, by which the air was suddenly admitted under the piston: equilibrium between the pressures above and below being thus restored, the rammer immediately fell with its whole force on the pile, bringing in its progress the piston again to the top of the cylinder, when, the slides being reversed, the operation was repeated. Thus a constant succession of short heavy blows

was given, and did not cease until the pile was driven to the required distance into the soil. And as, by the arrangement of pulleys, the distance between the pile-head and the rammer was always the same, a regularity of action was obtained, quite unknown in the old pile-driver.

Atmospheric Locomotives.—The cost, the weight, and the bulk of coal necessary to generate steam, have led many ingenious persons to attempt the discovery of a new power to work machinery, and, as the cheapest and most universal material, they have tried to use air for that purpose. The force existing in that elastic fluid, when compressed or rarefied, is the power that many ingenious men have been straining their inventive faculties to enchain and make obedient to their will; this has been effected with partial, not complete success.

At an iron foundry in Dundee was erected an air-engine, patented by Mr. Sterling. In this engine two strong air-tight vessels are connected with the opposite ends of a cylinder, in which a piston works in the usual manner. About four-fifths of the interior space in these vessels is occupied by two similar air-vessels, or plungers, suspended to the opposite extremities of a beam, and capable of being alternately moved up and down to the extent of the remaining fifth. By the motion of these interior vessels, the air to be operated upon is moved from one end of the exterior vessel to the other; and as one end is kept at a high temperature, and the other as cold as possible, when the air is brought to the hot end, it becomes heated, and has its pressure increased; whereas its heat and pressure are diminished when it is forced to the cold end. Now as the interior vessels necessarily move in opposite directions, it follows that the pressure of the enclosed air in the one vessel is increased, while that of the other is diminished; a difference of pressure is thus produced upon the opposite sides of the piston, which is thereby made to move from one end of the cylinder to the other; and by continually reversing the motion of the suspended vessels or plungers, the greater pressure is successively thrown upon a different side, and a reciprocating motion of the piston kept up. The piston is connected with a fly-wheel, in any of the usual modes, so as to communicate motion to machinery. A furnace is arranged to heat one end of the air-vessels, and a water-pipe refrigerator to cool the other; and the air traverses numerous small chan-

nels in its course from the one end to the other, in such a mode as to economise the heat.

Ingenious contrivances have been made public, for propelling railway carriages and other machines by the explosion of gunpowder continuously in small quantities, and also by the flashing into vapour of liquid carbonic acid and ammoniacal gases; but the public do not seem to like the idea of being sent to the end of their journeys by explosions and flashes, and the schemes have made no progress.

Some years ago an atmospheric carriage ran on the turnpike road from Putney to Wandsworth at a speed of twelve miles an hour. The air reservoir measured seventy-five cubic feet, and by the aid of a steam-engine the air was compressed to a force of fifty atmospheres, or about 700 lbs. on a square inch. From its discontinuance, and the example not being followed, we may justly suppose it was unsuccessful. In this and the other engine described, the motive power was *compressed air*; in others the *exhaustion of air* is resorted to as a means of traction.

Mr. Vallance at first proposed to form tunnels of sufficient dimensions to hold carriages; which being introduced at one end, the air was to be exhausted by a steam-engine at the other end, when the carriages would be shot along by the pressure of the atmosphere at the open end. The plan was considered ingenious, but not of practical utility. It was, however, suggested that the plan could be adapted to the transmission of letters, newspapers, &c., but no steps were taken for carrying the suggestion into practice.

In 1834, Pinkus brought forward a plan by which the carriages might travel outside the tube instead of inside, and this led to what is now known as the atmospheric railway (see below). An experiment at Wormwood Scrubbs showed that a load of six tons could be propelled at a rate of 30 miles an hour with a tube holding the piston rod of 9 inches diameter. The extension line of the Dublin and Kingstown Railway to Dalkey, a distance of about a mile and three quarters, required to have extremely steep gradients, frequently as much as 1 in 50 feet, and sharp curves. The usual locomotives being inapplicable, the atmospheric principle was called into requisition, and with a vacuum of 26 inches a speed of 35 miles an hour was obtained. The carriages returned by

their own gravity. The Croydon Railway, with a vacuum in the tube of 27 inches, obtained a speed of 60 miles an hour; on this railway a train of 10 carriages, weighing 50 tons, was propelled at a rate of 35 miles an hour. The diameter of the tube was 15 inches, the air-pump 6 feet 3 inches in diameter, the engines three miles apart, and a power of 300 horses employed for the whole distance. The steepest plane was 1 foot in 50. But the principle of atmospheric propulsion, from the frequent derangement of the mechanism, has been abandoned on this line, and locomotive engines adopted.

Pilbrow, in 1844, made several ingenious improvements in this system, but it has not gained approval from scientific men.

The following is a description of the principle and working of such an atmospheric railway.

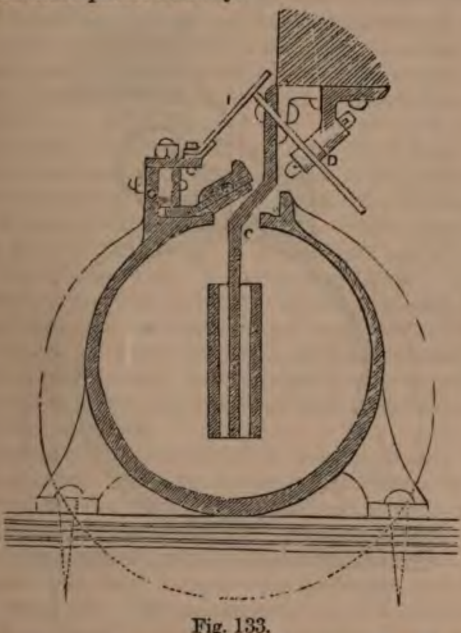


Fig. 133.

In the atmospheric railway, a pipe of about twelve inches diameter is laid between the rails on which the carriages run;

this pipe is exhausted at one end by an air-pump; a travelling piston is forced along it by the pressure of the atmosphere; and a rod, or plate, of iron, connecting the piston with the carriages, traverses a slit on the top of the pipe. The great difficulty to be overcome was to cover this slit with a substance which would be air-tight, and yet would permit the connecting-rod to pass without offering much obstruction. The plan adopted by Messrs. Clegg and Samuda, the projectors of the system as improved, will be best understood by reference to the accompanying diagrams.

Fig. 133 represents a vertical section of the pipe. The opening at the top is covered by a continuous valve G, extending the whole length of the pipe. It is formed of leather riveted between two iron plates. The upper plate is wider

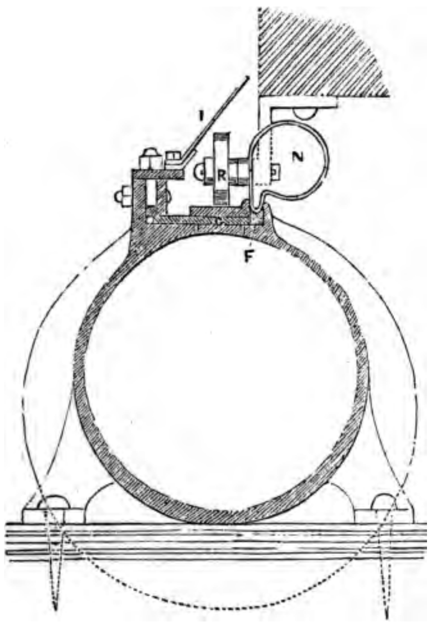


Fig. 134.

than the slit, and prevents the leather from being pressed in

by the pressure of the atmosphere; the lower plate just fits the slit, and is curved to the shape of the pipe. One edge of the leather is fastened to a longitudinal rib cast along the opening, and forms a hinge, as on a common pump-valve. The other edge of the valve, when it covers the opening, forms, with a ridge cast on the pipe, a channel or trough on its whole extent, a section of which is shown at F (fig. 134). This trough is filled with a composition of bees-wax and tallow, which, when melted and cooled, adheres to the side of the valve and keeps it air-tight. As the travelling piston is forced along the pipe, one side of the valve is raised by four small wheels fixed behind the piston, so as to admit the connecting rod C to pass as in fig. 133. The opening thus made also admits the air to act against the piston. The rupture thus made in the composition of wax and composition of wax and tallow is cemented again, before the train passes, in the following manner:—A steel wheel R (fig. 134), regulated by a spring, is attached to the carriage, and presses down the valve immediately after the connecting arm has forced it open, and a copper heater N, about five feet long, filled with burning charcoal, passes over the composition and melts it, thus leaving the valve air-tight as before, and ready for the next train. A protecting cover I, formed of thin plates of iron about five feet long, and hinged with leather, is placed over the valve to protect it from rain or dust. It was arranged to have each pipe about three miles long, with a stationary engine for each length of piping to exhaust the air; and another arrangement by means of which the piston, as it approached the end of the pipe, opened a valve and admitted it into the next length of piping, so that the train might proceed from the one to the other without stopping.

It is evident that as the tractive force is derived entirely from the pressure of the atmosphere on the piston, its amount will depend on the area of the piston, and on the extent to which the exhaustion of the air can be carried by the air-pump. It must also be evident that the difficulty of keeping the pipe air-tight will increase with its length, and with the pressure obtained. The vacuum-pipe on the branch of the Birmingham, Bristol, and Thames Junction Railway, where the atmospheric system is, or was, in operation for a few years, is only nine inches internal diameter, and but half

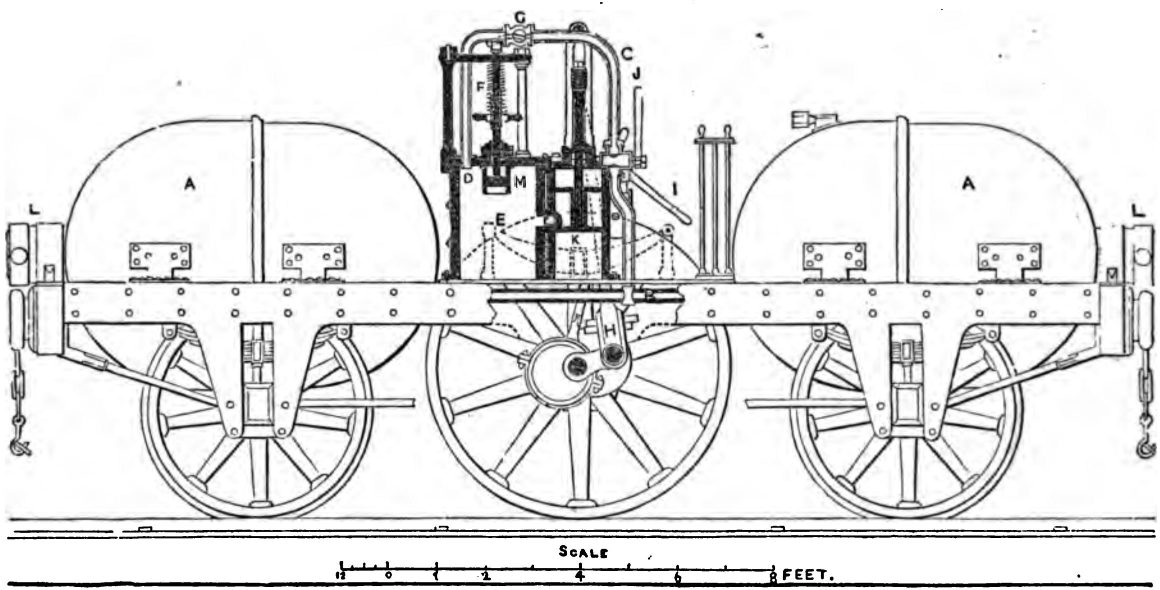


Fig. 135.

a mile long. A part is on an incline of 1 in 120, and part 1 in 115. A vacuum equal in some instances to a column of mercury $23\frac{1}{2}$ inches high has been obtained, and loads of 13 tons have been propelled at a speed of 20 miles an hour. On the Dalkey branch of the Dublin and Kingstown Railway, the pipe is 15 inches in diameter, and its length, so far as it has been tried, is one mile and a quarter. The average incline is 1 in 100; the exhaustion has been extended to $22\frac{1}{2}$ inches of mercury, and three carriages loaded with passengers have been propelled up the incline at a speed exceeding 40 miles an hour.

A stationary engine of 110-horse power would, it is stated, be adequate to exhaust a pipe of 18 inches in diameter, $2\frac{1}{2}$ miles long, in four minutes; and trains might be started each way every quarter of an hour, and convey daily 5000 tons.

The leather valve of the exhausting pipe is the weak point in these arrangements, and one which it seems cannot be improved upon. On the Croydon line *the rats* once eat the leather, and thus brought the whole to a standstill.

In 1846 Mr. Parsey exhibited in London a model of a locomotive air-engine which he had patented.

Fig. 135 is a side elevation of the entire carriage, with the working parts of the engine shown in section. Fig. 136 is an end elevation of ditto; and fig. 137 a plan of engine and part of air-vessels; the letters of reference corresponding in each diagram.

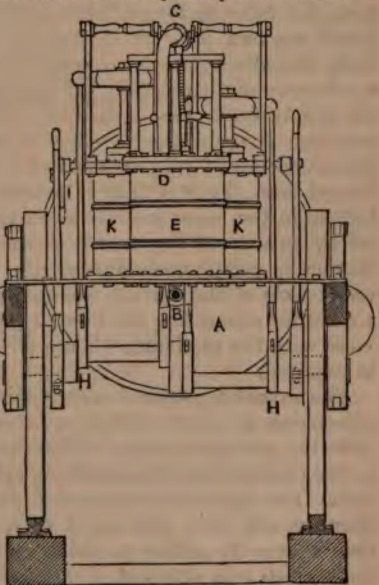


Fig. 136.

A A are receivers of compressed air; B, a tube connecting

the receivers, from which the air passes up the supply-pipe C into the equalizing cylinder E at D. Attached to the top of the equalizing cylinder E is a self-acting apparatus for adjusting the supply of air to the working cylinders K K; this is effected by setting the spring F so as to press down the valve M with a force equal to that at which the engine is to be worked, say 60 lbs. per inch. Whenever, therefore, the pressure in E becomes greater than that, the valve M is forced up, and partially closes the valve G; thereby limiting the supply from the receivers A A, and preserving a uniform pressure in E. The condensed air is conducted into the working cylinders K K through the sliding valves, in the same manner as steam, and is admitted or shut off by raising or depressing the handle of the stop-cock J. Motion is communicated from the cross-head direct to the crank-axle of the driving wheels by the connecting rods H H. L L are for connecting the hose or pipe of the stationary reservoirs with the receivers, when a fresh supply of condensed air is required.

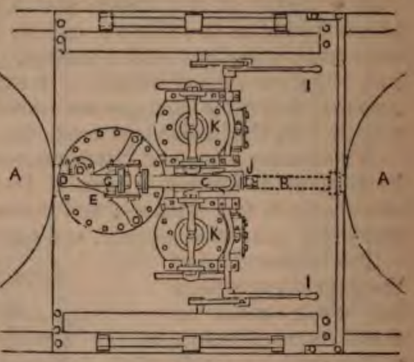


Fig. 137.

The inventor proposed constructing the receivers A A of his air-engine so as to sustain a pressure of from 1000 lbs. to 2000 lbs. per square inch; whilst the working pressure supplied to the engine from the equalizing cylinder would be 60 lbs. per inch. But this could be increased, and the speed thereby varied from twenty to a rate equal to a hundred miles per hour. One charge to suffice to drive an engine fifty miles, with a train of 40 tons attached.

It was also proposed to erect stationary engines on a railway line, at intervals of about thirty miles; from these a fresh service of air could be obtained as readily as the engines are at present supplied from the water cranes. Mr. Parsey stated

that the first cost of the engines, and the working of them, would be about half of the present expense of ordinary locomotives, while there was the advantage of tenders being unnecessary.

These inventions, doubtless, are very ingenious; they are the wonders of the day, but die a natural death, and are entombed among the numberless fruitless creations of man's busy brain. Compressed air will give out no more power than that expended in producing the compression, from which also has to be deducted the power necessary to overcome friction; but besides this there is another serious drawback that the enthusiastic inventor appears to overlook: on compressing air into a vessel a considerable amount of latent heat is roused into action, the natural consequence of which is a tendency to expand the air in the vessel, hence that expansion offers a resistance, to conquer which more power has to be applied that will not be returned; there is in fact, then, both the compression and expansion to be subdued. Again, on the compressed air being allowed to come in contact with the atmosphere, cold is produced, as we know when we contract the muscles of the chest, narrow the orifice of the mouth, and eject the air of the lungs with force; therefore there is at once a positive loss in air-machines, as the power generated by the heat, which had power expended upon it that it might be subdued, is entirely lost. The want of attention to simple principles has caused much labour to be fruitlessly expended.

Steam, and its application.

When a quantity of water is heated until it arrives at a certain fixed temperature, an elastic fluid or aqueous vapour is evolved; this is called steam, and resembles in many of its properties common air. Like air, it is elastic, capable of being reduced in bulk by compression; the pressure which it exerts in the vessel into which it is compressed being exactly in proportion to the amount of compression. Like air, steam is also capable of an increase of volume or bulk; this expansion reducing the pressure on the vessel in which it is allowed to expand just in proportion to the amount of expansion. The first property of steam now mentioned is termed its *elasticity*, the second its *expansibility*; although having these properties in common with fluid gases, steam is distinguished by the term

of aqueous vapour, inasmuch as it differs from a gas, which retains permanently its gaseous condition under ordinary circumstances; while steam requires to be kept at a uniform temperature, otherwise it changes its condition, and returns to its original form of liquid. This property, by which steam is readily converted into water, is of immense importance; by virtue of this property the power of steam is made available in what are termed condensing engines, and offers the readiest means of forming a vacuum in the cylinder, into which comparatively little force is required to press the piston.

When a quantity of water is placed in a boiler, and heat applied to it, a circulation of the particles of water immediately commences; those nearest the bottom, receiving a certain quantity of heat, expand and rise upwards; the colder portion, taking their place, and becoming heated in their turn, rise; small air-bubbles become formed at the bottom after the above process has gone on for a certain time; these bubbles contain aqueous vapour; these rise upwards, and on coming in contact with the colder portions above, are cooled or condensed, and give out their heat to the surrounding particles. This process continues until the whole mass becomes of a uniform heat, and a fixed temperature has been arrived at. After this, however long the heat might be applied to the boiler, the water would not increase in temperature; but the rising of the steam-bubbles would become so rapid that the whole mass would be in a state of agitation, and a vapour would be evolved in large quantities; this vapour, as before stated, is steam, and is invisible like common air. The fixed temperature already alluded to is what is termed the *boiling-point*. Under the ordinary atmospheric pressure at the level of the sea, the boiling-point of fresh water is 212° Fahrenheit, that of salt water being somewhat higher, or about 213°·2: in the generation of steam of a high pressure the boiling-point varies, increasing in proportion to the pressure. With a pressure of 16 lbs. to the square inch, the temperature at which the water boils is 216°·3; at 18 lbs. to the inch, 222°·7; at 20 lbs., 228°·4; at 25 lbs., 240°·9; at 30 lbs., 251°·4; at 35 lbs., 260°·6; at 40 lbs. to the square inch, 268°·8; at 50 lbs., 282°·7; at 55 lbs., 288°·8. The elastic force of steam is the same as the pressure under which it is evolved from the water. When steam is generated under a pressure of 15 lbs. to the square inch, it is termed

"steam of one atmosphere;" when generated at 30 and 45 lbs. to the square inch, it is said to be steam of two and three atmospheres respectively.

One of the most striking peculiarities of steam is the enormous increase of its bulk, as compared with that of the water from which it is generated. The proportion of increase will be best remembered by the statement, that under the ordinary pressure of the atmosphere, or 15 lbs. to the square inch, a cubic inch of water will produce a cubic foot of steam; and as there are 1728 cubic inches in a foot, the increase of volume in forming steam is (about) 1728 times. Under an increase of pressure the volume of steam is diminished: under a pressure of 30 lbs. the volume is only one-half; taking the "relative volume of steam" raised at a pressure of 15 lbs. at 1669, steam at 20 lbs. would have a volume of 1281; at 25 lbs., of 1047; at 30 lbs., or double the ordinary pressure, of 882; at 35 lbs., 766; at 40 lbs., 678; at 45 lbs., 609; and at a pressure of 50 lbs. steam would have the relative volume 554. Steam is capable of being reduced from a state of vapour by lowering its temperature; this temperature is always the same as that of the water from which it is raised. By gradually reducing the temperature of steam the vapour will be condensed, and reconverted into water; a cubic foot of steam under the ordinary pressure occupying the space of about a cubic inch of water.

In converting water into steam, a large amount of caloric is absorbed which is not observable by the thermometer; this is termed "latent heat." By this is meant the amount of heat required to evaporate a given quantity of water compared with that necessary to bring the water to the boiling-point. Thus it is found that to vaporize a certain quantity of water into steam at 212°, it will take $5\frac{1}{2}$ times as much heat as would raise the water from 32°, or the freezing-point, to 212°, the ordinary boiling-point; this excess of caloric, however, is not indicated by the thermometer,—hence the term *latent heat*. This heat is consumed and apparently lost in the transition from boiling water into steam. The latent heat of steam is reckoned at 1000°, the temperature of the steam being 212°; the sum therefore of the sensible heat, that is, the temperature indicated by the thermometer, 212°, and the latent heat 1000°, is equal to 1212°. The total amount of the indicated and latent heat

at all temperatures is a "constant sum:" thus if the pressure is increased at which the steam is raised, so as to give a temperature of 300°, the latent heat is 912°; if 500°, 712°, and so on. It is on account of this property of steam that so much fuel is expended in raising it.

The mechanical effect produced by the evaporation of a cubic inch of water is generally calculated as being sufficient "to raise a ton weight one foot high;" from this, however, is to be deducted loss from friction and other causes. "A pint of water," says Dr. Lardner, "may be evaporated by two ounces of coal. In its evaporation it swells into 216 gallons of steam, with a mechanical force sufficient to raise a weight of thirty-seven tons a foot high. The steam thus produced has a pressure equal to that of one atmosphere; and by allowing it to expand, by virtue of its elasticity, a further

Fig. 138.

mechanical force may be obtained, at least equal in amount to the former. A pint of water, therefore, and two ounces

of common coal, are thus rendered capable of doing as much work as is equivalent to seventy-four tons raised a foot high. . . . A pound of coke burned in a locomotive engine will evaporate about five pints of water. In their evaporation they will exert a mechanical force sufficient to draw two tons weight on the railway a distance of one mile in two minutes. Four horses working in a stage-coach on a common road are necessary to draw the same weight the same distance in six minutes."

The first employment of steam as a mechanical power may be traced back to a very remote period—to about 2000 years since—though then it was used rather as a toy than for any practical purpose, an application reserved for our own era. 120 years B.C., Hero of Alexandria caused steam to pass into a hollow globe which rotated freely on two pivots. From this radiated hollow spokes terminating in closed ends, near to which were small lateral orifices. The recoil produced by the escape of the steam from these holes caused the globe to rotate quickly. Had it been made to move a band passing round a pulley as is represented in fig. 138, this simple engine might have set in motion any machinery to which the other end of the strap was attached. In fact, rotary engines, on this very principle, have been lately revived, and are now working in this country.

In the year 1543, if we may trust to some documents recently exhumed from the national records of Spain, the use of steam as a motive force was brought forward in a practical manner. A certain Captain de Garay proposed to the Emperor Charles V., to carry ships out of the harbour of Barcelona against wind and tide. The experiment was made publicly. It was crowned with success. His boat, containing the apparatus, of which all that could be discovered was that it consisted of *a caldron of boiling water and two wheels,* succeeded in moving at the rate of nine miles in two hours. The discoverer was rewarded; but the heart of the emperor was set on other enterprises; the *first steam-boat* was broken up, and a conquest far greater than any of those on which his heart was set, was lost for ever to Charles V., and for more than 200 years to the world.

However, in 1615, a Frenchman or German, named Solomon de Caus, in a work published at Frankfort, described a machine (fig. 139) in which the pressure of steam acting on the surface

of water boiling in a close copper vessel, caused some of the water to pass up in the form of a jet through a tube which passed through nearly to the bottom. He made also a further advance towards the application of steam to motive purposes. Having engaged in various engineering labours at Heidelberg, and at Richmond in England, he went to Paris, where, on attempting to bring his inventions under the notice of Cardinal Richelieu, he was confined by him in the Bicêtre for a madman! While imprisoned here he received a visit from the exiled Marquis of Worcester in 1641, who seems to have derived from him his idea of the use of steam power. However, it is remarked by Dr. Lardner, that the invention of this nobleman was a marked advance upon that of De Caus, as he used steam much as it is employed at the present day, generating it in one vessel, and employing it for mechanical purposes in another. Lord Worcester, too, used his machine for forcing water up a pipe, but the power used was constant, the steam being generated in a separate boiler, which could be continually refilled, and passed thence along a pipe into the upper part of a vessel resembling in principle that constructed by De Caus.

Fig. 139.

Some time after this the French philosopher Papin invented a plan by which a piston could be moved up and down in a cylinder by means of steam. The steam admitted beneath it, forced it up; the steam was then condensed, when a vacuum was produced, and the piston forced down. This, though thought little of at the time, was a discovery of the utmost importance.

In 1705, Newcomen, a Cornish engineer, constructed a working engine on this principle. It was used to raise water, and the steam employed was of very low power, all that was

needed being the alternate depression and elevation of a horizontal beam *i*, communicating at one end with the piston *n*, in a vertical cylinder *c*. Beneath the piston were two cocks *n k*,

Fig. 140.

worked by the same handle, one admitting low-pressure steam into the cylinder, which forced up the piston; then the other being opened while the first was closed, admitted cold water, which condensed the steam, causing a vacuum and bringing the piston down again.

In 1765 the steam-engine was brought as near as possible to perfection by the celebrated engineer James Watt. He made two great improvements on the plan of Newcomen. Instead of admitting cold water into the piston cylinder, he allowed the steam to pass at the proper moment into a *condenser* surrounded by cold water; and instead of allowing the piston to be depressed by the weight of the atmosphere (as by

condensing steam beneath), he arranged that it should be both raised and lowered by steam, which was admitted into the cylinder above and below the piston alternately. In order to produce rotatory motion by the ascent and descent of the piston, various ingenious contrivances were successively adopted by Watt. To control the pressure of steam, he introduced into the steam-pipe a valve called the *throttle valve*; this he connected with a lever placed in connexion with an apparatus called the *governor*.

We now give a cut of the modern steam-engine, the grand practical result of these various inventions. The steam-boiler is not shown. Among various ingenious contrivances connected with the boiler are, a gauge to indicate the pressure of steam; a safety valve to be opened by the steam when of too high pressure; gauge cocks to show the quantity of water in the boiler; a manhole for entrance to clean it when not in action, and a cock at the bottom to empty out the water.

From the boiler the steam passes by the steam-pipe B (fig. 141) into the cylinder A. In the pipe is the throttle valve C, which can be regulated to a nicety by the governor D. At each end of the cylinder, on one side, is an oblong box E, communicating with it. In the upper box are seen two valves, a valve of induction, admitting steam into the cylinder F, and a valve of exhaustion, permitting the steam to pass out to the condenser G. In the lower box are two similar openings, the induction valve *g*, the exhaustion valve *f*.

By the exhaustion valves the steam passes down into the condensing cylinder K, into which cold water is admitted through the rose I. This condenses the steam, and the hot water thus formed passes into an adjoining cylinder J, whence it is pumped off into an upper cistern *j*, by the vertical working of the rod and piston L. This piston-rod is fixed to the beam of the engine and works with it. Attached to this piston-rod are two pins, which catch the lever H in ascending and descending. This lever is called the *spanner*. It regulates the action of all the four valves, of induction and exhaustion.

The action of the engine is as follows:—The two vertical pistons move simultaneously, the one regulating the other. Suppose the pistons to be at the top of the cylinder. F and *f*, the upper induction valve and the lower exhaustion valve, are now opened simultaneously by the action of the spanner, the

other valves being closed. Steam is thus admitted above the piston, the steam below being drawn off into the condenser. The piston is pressed down to the bottom, drawing down the end of the beam to which it is fixed. This depresses the piston of the pump L, the pin attached to which catches the spanner, and

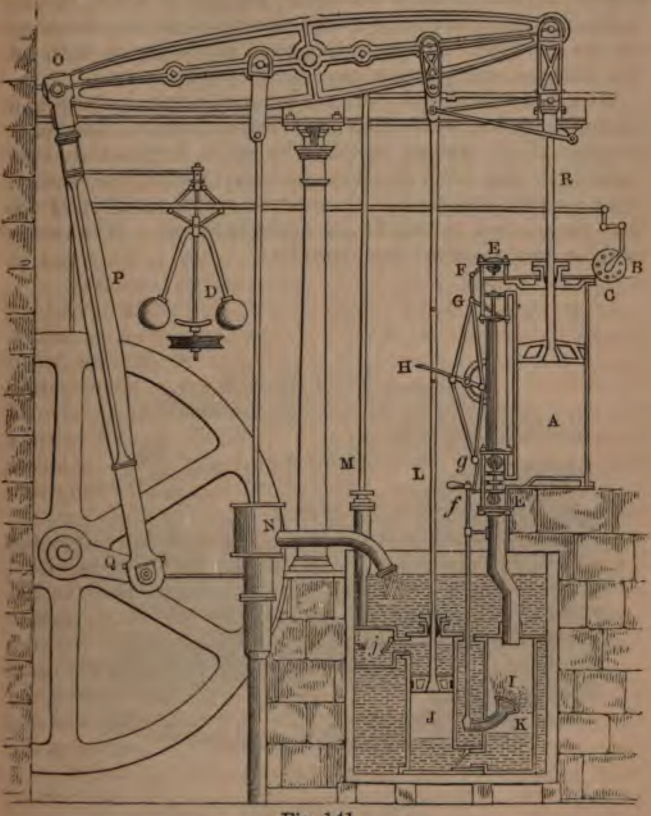


Fig. 141.

now the valves last opened are closed, and G g, the upper exhaustion and lower induction valves, are opened. Steam enters below the piston, while that above is allowed to pass

out. The piston is thus raised, raising the beam, &c.; again the spanner acts, and so on. All this while the steam is being condensed below, and the water pumped out, as before said.

The *governor*, which resembles a pair of tongs with the legs stretched out, regulates the quantity of steam admitted to the engine; should there be too much, the legs fly apart, and, by a contrivance, close a valve in the pipe which admits the steam to the cylinder. The *fly-wheel* gives regularity of motion to the machine, and prevents any check upon its motion.

Attached to different parts are numerous rods, by which the engine becomes self-acting and self-adjusting, marks the number of its strokes, supplies its boiler with water, feeds itself with coal, takes oil when necessary, with a damper regulates its heat, will slacken the fire with water, and in helplessness rings a bell to call for its attendant's aid. What writer of fable ever conceived such marvels?

Fig. 142.

CHAPTER VII.

ACOUSTICS, OR THE PHYSICS OF SOUND.

The word Acoustics is derived from a Greek word signifying to

hear. The science of Acoustics treats of all that relates to sound. Sound consists of a number of rapid vibrations in the air, or other medium, of such a nature as to be apprehended by the organ of hearing.

When a bell is rung under an exhausted receiver of an air-pump, scarcely a sound is audible. The same bell struck in the open air is distinctly heard, *for the air is the usual medium through which sound is conveyed.*

Place a wine-glass mouth downwards on a table, and tap it sharply with the finger-nail, the blow is merely heard; but raise it up and then hit it, and a musical sound rings on the ear, which will be increased by slinging it with a piece of string. This arises from the circumstance, that when held gently by the hand, the glass is free to vibrate in the air, and more so when slung from the cord; *for vibration is necessary to sound.* The agitation of the glass from the blow gives impulse to the air by which it is surrounded, in the same manner as water undulates in circles when a stone has been thrown on its peaceful surface; and these aërial waves coming in contact with the drum of the ear, the nervous membranes convey the impression of sound to the mind.

Some sounds differ in intensity; thus if one sound drowns another, it is simply said to be more intense, provided it be of the same note; others differ in pitch, as the high and low notes of music; and others in character, as the tone of the same note sounded on two different instruments. So wonderfully delicate and acute is the organization of the human ear, that man can hear and distinguish almost any number of different sounds at the same time.

A rapid motion given to certain objects, as those of the prongs of a tuning-fork, the strings of musical instruments, the coverings of drums or gongs, and other contrivances, produces sound; the agitation that ensues communicating itself to the surrounding air, a succession of vibrations ensues, which reaches the ear and is called sound. But the particles of air in contact with the ear must vibrate at least thirty times in a second before the impression of a musical note can be received.

The atmosphere around us, if moved in a body and with the same velocity, produces no sound; a high wind must be driven against some obstacle before the voice of the hurricane is

heard. The booming of cannon, or the joyous peal of a bell, is borne in agitated waves along the atmosphere, in whatever direction the wind may blow; but neither they nor the sound of a thousand brazen instruments produce the slightest degree of wind in any direction. Still when a powerful instrument is sounded near to a table on which glasses are placed, they will be observed to tremble, and may even fall to the ground on account of the vibration produced.

The aërial ocean in which man lives, is the general medium through which sound is conveyed to his senses, being in direct communication with the tympanum or drum of his ear; but other bodies, solid or fluid, having their particles of matter closer than air, when possessed of a moderate degree of elasticity, if placed between the exciting cause and the ear, form mediums for the conveyance of sound. The velocity of sound in air is 1125 feet per second. A bell rung under water has been distinctly heard at a distance of nine miles, which must have sped at the rate of 4708 feet per second. Thus it is found by accurate calculation, that sound travels more than four times more quickly in water than in air. If a person scratch one end of a long piece of timber with a pin, and another person apply his ear to the other end, the noise can be distinctly heard by the person at the distant end, although not by him using the pin. The same applies to the ticking of a watch, that only a few feet distant with the medium of air could not be heard; this sound is also conveyed from ten to twenty times quicker through this solid than through the air. The earth likewise is a good conductor of sound; and we read of North American Indians laying their ears to the ground, to discover the approach of human enemies or beasts of the forest. The miner hears through the solid rock the pickaxe of some neighbouring labourer, and the besieged detect the approach of a subterraneous enemy, from the sound conveyed by the earth. The physician applies the end *a* (fig. 143) of the stethoscope to the chest of his patient, and hears the operation of breathing, and the rushing of the blood in the heart, by applying his ear to the end *b*. On placing a wooden or iron bar against a tea-urn or kettle, and the opposite end against the ear, a tumultuous roaring and bubbling is heard, and the boiling of the

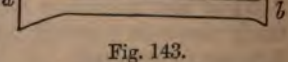


Fig. 143.

water ascertained. Iron conveys sound seventeen times faster than air. If, with closed ears, the teeth or temple be placed against a long piece of timber, having at the other end a watch, the ticking will be distinctly heard. This is the case as long as the nerve of the ear is uninjured, the sonorous vibrations being conveyed by the solid bodies of the teeth and cranium to the nerves of the ear.

Sound is not conducted well from one medium to another, except when they are of similar density. Thus, on putting the head beneath the water of a bath, no sound is heard from the world outside.

Wind, as every one has practically experienced, retards or accelerates sound. The booming of cannon in a naval engagement has been heard at the distance of two hundred miles. A whisper and the report of a cannon travel at the same speed; thus a sound may be made loud by a powerful blow, but nothing is added to its velocity of propagation. At 62 degrees of Fahrenheit's thermometer sound travels at the rate of 1125 feet per second; a cannon-ball has about the same velocity, but at every foot its speed is lessened; whereas the noise accompanying its start on its destructive mission continues onward with the same speed as at first, only diminishing in intensity until it dies away in space.

Peschel gives 345 miles as the greatest known distance to which sound has been carried in the air. This was when the awful explosion of a volcano at St. Vincent's was heard at Demerara. The earth, as has just been said, conveys sound better than the air. The cannonading of the battle of Jena was just heard in the open fields near Dresden, a distance of 92 miles, and in the casemates of the fortress it was very distinct. The bombardment of Antwerp in 1832 is said to have been heard in the mines of Saxony, 370 miles distant!

Sound travels a mile in about four seconds and three quarters; $12\frac{3}{4}$ miles, equal to 67,500 feet, in a minute, or 767 miles in an hour.

Thus if a flash of a musket be seen, the distance may be easily ascertained by timing the arrival of the report. When lightning bursts from the clouds, by laying the fingers on the wrist and counting each pulsation as a second until the thunder is heard, its distance may be pretty nearly calculated. But for every increase of one degree of temperature the velocity

[illegible] every [illegible] very [illegible] per [illegible]

[illegible] is at [illegible] under [illegible] atmo- [illegible] better [illegible] less [illegible]

[illegible] This [illegible] exist- [illegible] of matter. [illegible] undu- lation [illegible] a tight string [illegible] undergoes [illegible] thus wave [illegible] a tight string [illegible] actually see the [illegible] seen in the [illegible] tuning-fork [illegible] vibrations are transmitted to the air, the particles of which vibrate in a similar though unseen manner. [illegible] passed on to the membrane of the ear, this vibrates in contact with a chain of bones which transmit the sensation to the auditory nerve; and the *sound* is [illegible] appreciated by means of a sense formed for that very purpose.

The character of sound-vibrations may be rendered evident to sight by many simple contrivances; as by a ball hung by a string to a bell,—by pieces of paper on a violin-string—or by sand placed on the sounding-board of a piano or any other stringed instrument. When, again, musical notes are produced by drawing the wet finger round the edge of a glass containing some water, waves will be seen undulating from the sides towards the centre.

If we strike a tuning-fork, and then touch a surface of mercury, waves will be produced corresponding to the tremor giving rise to the *tone*. If we touch a glass disc, or hold a tuning-fork over an open cylinder, or a glass which has any

fine dust upon it, or water in it, we may render the vibrations very apparent; and the mode of exciting and maintaining the vibrations of a column of air may thus be shown:—Take a common tuning-fork (fig. 144), and on one of its branches fasten, with sealing-wax, a circular disc of card of the size of a small wafer, which will cover the aperture of a pipe. If the fork be set in vibration by a blow on the unprepared branch, and the disc be held close over the mouth of the pipe, a note of great strength and clearness will be heard.

Fig. 144.

In the line of undulation of a string or other body which is sounding, there may be distinguished certain points of rest between the waves. Thus, in a piece of catgut fixed at each end *b* (fig. 145), the points marked *a* may be still, while on either side waves rapidly alternate in opposite directions, as represented by the bowed lines. Such spots are called *nodal points.* The motions on the line at the intervening spaces resemble the oscillations of the pendulum, in being equal in extent and time, and continue thus as long as the sound lasts.

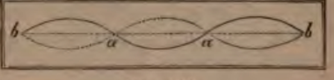


Fig. 145.

The number and rapidity of vibrations in a line or rod is increased in proportion to its tension. It is also increased in proportion as its length is lessened.

If we strew some fine sand on plates of glass, and elicit sounds from these by drawing the bow of a violin across their edges at various points, the sand will collect on the points of greatest rest, and thus *nodal figures* may be formed in which the curving lines will represent accurately the direction of each wave of vibration. The examples i

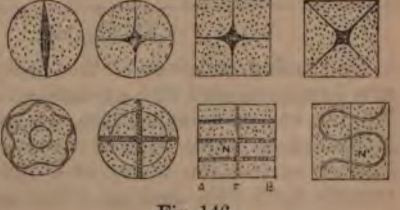


Fig. 146.

[illegible]

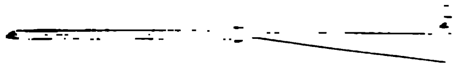


Fig. [illegible]

[illegible] surface. [illegible] of metal [illegible] similar surface [illegible].

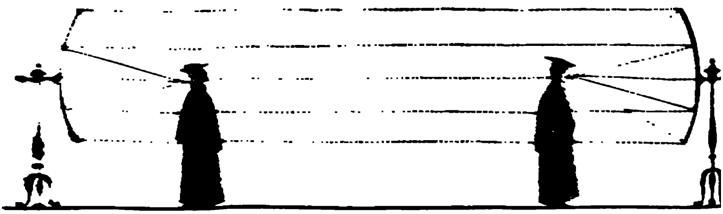


Fig. 1[illegible].

By availing ourselves of this principle of reflexion, sound may be concentrated with advantage. By speaking or blowing into the end of a hollow pipe, we procure a sound which is intensified in three several ways. By reflexion from its interior surface the waves of sound are driven to a focus towards the further opening. The air, being compressed into a confined space, is made to vibrate with far greater effect than usual. And thirdly, the material of the tube, if apt [illegible] the production of sound, catches the note, and also

vibrates intensely. These causes combine to produce the loud note of a *trumpet*, and concur variously in other wind instruments.

The *ear-trumpet* enables deaf persons to hear by the sound of the voice being brought to a focus at the narrow end, thus increasing the intensity of sound upon the ear. The *speaking-trumpet* concentrates sound, and directs it to a particular part, above the voice of the storm. The alcoves on Westminster Bridge (fig. 149), long since removed, were so truly constructed

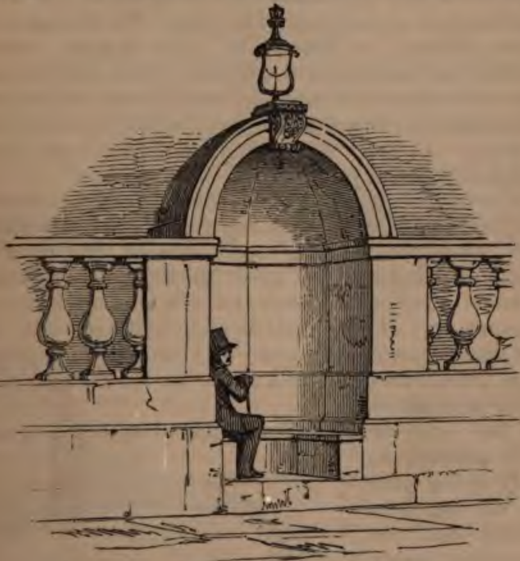


Fig. 149.—Alcove on Westminster Bridge.

in architectural proportions, that on a still evening a whisper in one might be heard in another on the opposite side of the road. But one of the most perfect instances of this peculiarity of sound is the Whispering-gallery of St. Paul's Cathedral, which is 430 feet in circumference. Seated in this gallery, the attendant, by whispering against the side 140 feet from the visitor, is heard as distinctly as if close to the ear.

As the waves of water are thrown back when they meet

with an obstruction having a smooth surface, so are the waves of air creative of sound: this constitutes an echo.

The flat sides of rocks, mountains, caves, domes, and arches, thus reflect sounds. There are several very remarkable echoes in our islands; among the most striking are the following:—An echo in Woodstock Park, Oxfordshire, repeats seventeen syllables by day and twenty by night. In Gloucester Cathedral, an echo conveys a whisper 75 feet across the nave. The suspension bridge across the Menai Straits repeats a blow with a hammer twenty-eight times in five seconds. On the Lakes of Killarney is a remarkably fine echo. On the north side of Shipley Church, in Sussex, an echo repeats twenty-one syllables. At Lurley, on the Rhine, a noise made on one side of the river is echoed and re-echoed across and across in a zigzag manner, proceeding onwards about six times, when it dies away. In some places the report of a pistol has been counted as many as forty times.

As we commonly utter about three syllables and a half, or seven half-syllables in a second, the echo of this number of syllables will be distinctly heard in that time by a person situated at the distance of about 560 feet, half the number of feet sound travels in a second; but if a sentence be continued, the sounds will so commingle as to be confused.

As sound travels at the rate of 1125 feet in a second, by timing the arrival of an echo to the ear the distance of places may be ascertained.

If the waves of air strike obliquely against a wall, they will be reflected obliquely on the other side, the angles of incidence and reflexion being equal. The irregularity of surface in a wall may be so great as to prevent entirely any distinct reflection: this is the case in theatres, the walls of which are provided with broken surfaces to prevent the echo. A regular

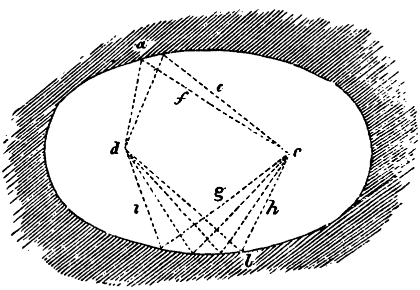


Fig. 150.

concave surface concentrates sound. In a perfectly circular room the waves of sound are concentrated in the centre. Elliptical or oval-shaped rooms present a curious property in the concentration of waves of sound. This property is such that waves of sound proceeding from one of the foci *c* of an elliptical room *a b* (fig. 150), after reflexion at various points, as from the lines *e, f, g, h, i*, are all concentrated in the other focus *d*; thus a person whispering at *d* can be heard distinctly by another standing at *c*, although it is not audible to other parties elsewhere situated in the room.

The Human Ear.

The ear forms one of the most important channels of connexion between the mind and the external world.

The external passage of the ear (fig. 151) is terminated by the membrana tympani, which is very elastic, having behind it the tympanum; and from this is a tube for air from the throat, which accounts for persons aiding their hearing by opening the mouth. Deeper than the tympanum, which contains a chain of bones, are two closed chambers, called cochlea and vestibule,

Fig. 151.

which are filled with a watery fluid, in which are expanded the fibres of the auditory nerve. When sounds reach the membrana tympani (fig. 152), it is set in motion; this is communicated to the small bones, named after their fancied resemblance to certain implements, the *malleus, incus, orbiculare*, and *stapes*. Their use is to transmit the vibrations of sound from the external membrane to the fluid contained in the internal ear, and to the nerve spread out in this fluid. They have another use that a single bone could not be made to perform; namely, to permit the lightening and relaxing of the tympanic membrane, and thus adapt it either to resist the impulse of a very loud sound or a more gentle one. Mammals alone have external ears. Birds have but a simple aperture; in reptiles and fishes the ear is covered over with skin: in many animals, crabs for example, it consists merely of a vesicle filled with fluid, throughout which the nerve is spread out.

An old story is told of Dionysius, the tyrant of Syracuse. He made a subterraneous cave in a rock (said to be still pre-

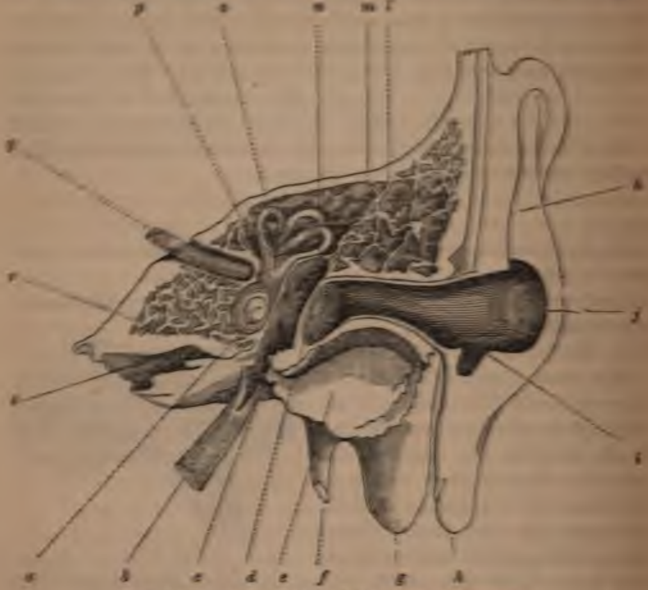


Fig. 152.—A vertical section of the human ear.

a. Is named the cochlea, from its resemblance to a small shell.
b. Eustachian tube, leading from the tympanum to the back of the throat.
c. The tympanum, in which are four small bones: the malleus, or hammer; the incus, or anvil; the orbiculare, or little ring; and the stapes, or stirrup. In it are two openings, called fenestra ovalis and rotunda.
d. The membrana tympani.
e. The glenoid fossa of the temporal bone, in which the lower jaw is articulated.
f. The styloid process of the temporal bone.
g. The mastoid process of the temporal bone.
h. External lobe of the ear.
i. The antitragus.
j. Conch of, or entrance into, the ear.
k. The tragus.
l, m, r. Petrous portions of the temporal bone.
n. Opening from the cavity of the tympanum to the cells of the petrous bone.
o. Semicircular canals.
p. The vestibule.
q. The auditory nerve.
s. Canal through which the internal carotid artery enters the cranium.

served), in the form of a human ear, which measured 80 feet in height and 250 feet in length. The sounds of this subterranean cave were all directed to one common tympanum, which had a communication with an adjoining room, where

Dionysius spent the greater part of his time, to hear what was said by those whom his suspicion and cruelty had confined. The artists that had been employed in making this cave were all put to death by order of the tyrant, for fear of their revealing the purposes to which a work of such uncommon construction was to be appropriated.

Music.

Such is the delicacy of the human ear, that it can distinguish readily between two sounds, the one having 400 vibrations in a second and the other 405; even between different instruments playing the same note, and between two of the same kind of instruments when playing together; or detect a single voice amid hundreds all singing the same tune. The *hearers* of an orchestra are employed in discriminating between various rates of succession in the undulations of the air around them, from 60 to 2000 per second.

If a piece of catgut or wire be slightly stretched, and then hit or pulled at the middle, it will be seen to vibrate, and each pulse of the air be separately heard; but when tightened and struck or pulled, the vibrations follow in quick succession, only a broad indistinct line is seen, and the pulses of the air follow so rapidly, that they are felt on the ear as one tone, which is called a note. The uniformity of tones in elastic strings arises from large vibrations occupying about the same time as smaller ones. When the vibrations are rapid, the sound is loud, from the pulses of the air being more forcible. The regularity of succession of the pulses of the air produces the pleasing effects of a tone, as the buzzing heard from the quick and regular movement of the wing of a fly.

If we examine the strings of a violin, we see that one is carefully wound round with a fine metal wire; this makes it thick and heavy; it must have a slower vibration than thinner ones, therefore produces a bass or grave note; and the others vary in thickness, have quicker vibrations and sound, higher or sharper, and are screwed up to a certain tension to assist the perfection of tone. Then a quicker vibration is produced from shortening the string by the pressure of the finger or by tightening, and slower vibrations by lengthening the string or slackening it.

There are seven primary notes in music, which are those

that would be used by a person who had not learnt it scientifically. They are expressed in singing by the names of Do, Re, Mi, Fa, Sol, La, Si, and in printed music by notes arranged and named as the following letters of the alphabet, C, D, E, F, G, A, B.

The pitch of the different musical tones are represented to the eye by employing five parallel lines, called a staff, or stave, the degree of pitch being shown by characters placed upon those lines or on the spaces between them, as in fig. 153, these characters being called *notes*; the whole in this example representing one octave and part of another.

Fig. 153.

If a musical string be of such a length and tension that it gives out in a second 258 vibrations, according to M. Biot the note will be C; but if only half the length be used, the vibrations will be twice as many as before, 516; this commences a new series of notes, another C or eighth letter, and is termed an octave. If the string be reduced to eight-ninths there will be 290 vibrations, the note D; if to four-fifths 322 vibrations, the note E; if to three-fourths 344 vibrations, the note F; if to two-thirds 387 vibrations, the note G; if to three-fifths 430 vibrations, the note A; and if to eight-fifteenths 483 vibrations, the note B. A string when touched not only gives out its primary note, but subordinate notes belonging to its half, third and fourth. By watching the motion of a string, it will be found vibrating not only along its whole length, but also at the same time vibrating in shorter lengths, thus sometimes the subordinate notes are more distinctly heard for a time than the original. It is this natural and self-acting division of a string into equal parts that produces the wild music of the *Æolian harp*. The cords are tuned to the same pitch, but as the passing breeze touches various parts, either a perfect note is heard, or some of the divisions in vibration of which each string is susceptible.

The Æolian harp (fig. 154) may be constructed in the following way:—" Let a box be made of thin deal, of a length exactly answering to the window in which it is intended to be placed, four or five inches in depth, and five or six in width. Glue on it, at the extremities of the top, two pieces of oak, about half an inch high and a quarter of an inch thick, to serve as bridges

for the strings; and inside, at each end, glue two pieces of beech about an inch square, and of length equal to the width of the box, which are to hold the pegs. Into one of these bridges fix as many pegs, such as are used in a pianoforte, though not so large, as there are to be strings; and into the other, fasten as many small brass pins, to which attach one end of the strings. Then string the instrument with small catgut, or *first* fiddle-strings, fixing one end of them, and twisting the other round the opposite peg. These strings, which should not be drawn tight, must be tuned in unison.

Fig. 154.—The Æolian Harp.

To procure a proper passage for the wind, a thin board, supported by four pegs, is placed over the strings, at about three inches distance from the sounding-board. The instrument must be exposed to the wind at a window partly open; and to increase the force of the current of air, either the door of the room, or an opposite window, should be opened. When the wind blows, the strings begin to sound in unison; but as the force of the current increases, the sound changes into a pleasing admixture of all the notes of the diatonic scale, ascending and descending, and these often unite in the most delightful harmonic combinations."

The lowest note that can be heard has 30 vibrations in a second, and the highest 8192, between which there are about eight octaves. The human voice possesses a power of from two to three octaves, a man having a pitch an octave lower than a woman. An organ-pipe 32 feet long produces a very deep note, having waves of sound 32 feet long, and the same number of vibrations in a second; this is note CCC; its octave has 64 vibrations in the same time, its third 40, and so on.

[illegible] may be given by [illegible] producing a given [illegible] a difference. [illegible] the manner in which [illegible]

[illegible] in the same plane. [illegible] and very [illegible] different man[illegible] the crude [illegible]

[illegible] that we have given, is that [illegible] has expressed [illegible] he uses. The [illegible] vibration of two [illegible] having an opening [illegible] according to the [illegible] and the size of the [illegible] according to the note [illegible] thirds, fifths, and octaves [illegible] together, more than [illegible] in proportion, [illegible] gratifying to the ear. [illegible] expected sound, and thus [illegible]

We may add, that the concert pitch has progressively risen all over the world.

Musical sounds are produced in many ways, as by elastic metal wires; prepared strings of animal intestines; pieces of metal cut like a comb, having a barrel with prongs to cause them to vibrate; the stretched skins of sheep; hollow vessels of brass, confining a column of air in a tube; a glass or pieces of glass, a bell; or, as in the organ, admitting a column of air from bellows to pipes by the action of keys; or by thin pieces of reeds or metal, which vibrate from the breath being applied, and according to their elasticity, weight, or length, give forth their peculiar tones; and these different means of producing sounds give rise to the varied shapes of musical instruments.

M. Faber made an attempt, by the aid of machinery, to imitate the human voice; he called his invention "The Euphonia" (fig. 156), and stated it to be the result of twenty-five years' labour! It is quite true that mechanical figures, in turbans, with their lungs in red baize and worked by machinery, are not in themselves useful—the more particularly as all

Fig. 156.—The Euphonia.

talking machinery requires the impulse of a real living and talking man, who might more conveniently have done the talking at first hand; but as an example of inductive and mechanical ingenuity, however, such an exhibition as this is well deserving of attention; and there is no difficulty, besides, in

imagining a number of purposes to which the discovery of any artificial means for producing vocal articulation might be applied with valuable effect. It is, in any case, an old scientific problem; and anything that brings us nearer to its solution would have an interest, were it for that reason alone. We believe this invention of Professor Faber comes closer to that result than any previous "instrument made with hands." Still, this is, like all similar attempts which have preceded it, only an approximation, though a nearer approximation, to the thing proposed. It requires something more than a full knowledge of the ingenuity and perseverance which appears to have been bestowed on this work, to induce us to give our assent to the proposition, that a sound of the kind produced, deserves to be dignified by calling it a *human voice*; indeed the machine is only remarkable as the result of patient industry and scientific skill.

Voice and Speech.

The chest and air-passages, with their parts, constitute the organs of voice and speech. An inquirer into the constitution of the universe around him meets with few things calculated more to surprise him, than the faculty in the human mind by which it can so closely associate the ideas of objects with any arbitrary signs, that the ideas are afterwards excited by the signs almost as vividly as by the objects themselves. The inhabitants of China, for instance, have contrived many thousand grotesque characters, and determined what object each one shall recall; and a person who by study becomes familiar with them, may have his bodily eye poring over pages of crooked and unseemly scratches, while his mental eye sees only a pleasing succession of the most beautiful imagery of nature; and the characters are intelligible to the deaf and dumb man as well as to him who speaks; and they serve as media of thoughts and communications through many provinces and countries of which the spoken languages have no common resemblance.

If the ready resemblance of visible marks be wonderful, which have permanent existence, and often a certain resemblance of the things signified, how much more wonderful is it that an audible sign, that is, a passing sound or fugitive breath, should serve as well; and that by a succession of mere sounds,

different in every country and changing from age to age, any train of thoughts may be made to pass through the minds of an audience, so as to leave impressions almost as strong as from realities! Such, however, is the fact; and it is greatly owing to this and to a corresponding faculty of producing easily a sufficient number of distinguishable sounds, that man owes his elevation above the brutes of the field.

His godlike powers of intellect would have remained dormant and unknown, had he wanted the power of comparing his invisible thoughts with those of his fellow-men, and of arranging and recording them by means of signs.

Written language is a double remove from the objects themselves, being *visible signs*, not of things, but of the *audible signs*.

The admirable apparatus by which man is enabled to produce a sufficient variety of sounds to answer his purposes passes generally under the title of *the organs of speech*; because the combination of sounds which have meanings assigned to them is called speech. It consists of the chest for containing air, of the larynx or cartilaginous box at the top of the windpipe for producing the voice, and of the short tube of the mouth for modifying it.

We have already explained that sound is the name given to the effect produced upon the ear by certain tremblings conveyed to it, generally through the medium of the air; this air, rushing from the human lungs through the opening at the top of the windpipe, may be modified at the will of the individual, in a great variety of ways—a variety which is, however, still very simple.

The modifications of voice easily made, and easily distinguishable by the ear, and therefore fit elements of language, are about fifty in number; but no single language contains more than about half of them. They are divisible into two very distinct and nearly equal classes, called *vowels* and *consonants*.

Those of the first class are the simple voice issuing through the open mouth, and influenced only by the degrees in which the mouth is opened and elongated. They may be continued as long as there is breath to issue from the chest, and therefore are named *vowels* or *calling sounds*. The Roman letters A E I O U, as generally pronounced on the continent of Europe, indicate the most easily distinguishable vowels. Sounds

passing through the mouth while in its most natural state of relaxation, are heard as the modification expressed there by the Roman E (or the *a* of the English word *care*); if the mouth be then widened, it becomes A (of the English word *bar*); if narrowed, we hear I (or *ee* of the English word *seem*); if the mouth be elongated, and at the same time widened, we hear O; and if elongated and narrowed, we hear U (of the English word *rude*). The possible number of vowels, however, is as great as the possible degree in which the dimensions of the mouth may be altered. About twenty of them are sufficiently distinguishable; but few languages comprehend so many. Modern art can produce the vowel sound mechanically, by means of tubes of certain dimensions.

The alphabets of Europe are very faulty in not using the same characters for the same sounds, and in not having a character for each sound, according to the true intent of the alphabet. In English one letter is used for several sounds, as A in *water, far, fat, fate,* which are four perfectly distinct sounds.

In repeating the English alphabet, the A is pronounced as a broad E of the Italians, and the E as the I. The English vowel I is the diphthong AI of the more correct alphabets; and the English U is the diphthong IU. In consequence of the changes which have taken place in England in the meaning of the Roman letters, the difficulty natives experience in learning modern continental languages is often great, and unintelligible to all but themselves. The same cause renders the pronunciation of English difficult to foreigners, and thus much restricts the cultivation of English literature in other countries.

To explain the second class of the modifications of sound, called *consonants,* we may remark, that while any continued or vowel sound is passing through the mouth, if it be interrupted, whether by a complete closure of the mouth or an approximation of parts, the effect on the ear of a listener is so exceedingly different, according to the situation in the mouth where the interruption occurs, and to the manner in which it occurs, that many most distinct modifications thence arise. Thus any continued sound, as A, if arrested by a closure of the mouth at the external confine or lips, is heard to terminate with the modification expressed by the letter P, that is, the syllable

AP has been pronounced; but if, under similar circumstances, the closure be made at the back of the mouth by the tongue rising against the palate, we hear the modification expressed by the letter K, and the syllable AK has been pronounced; and if the closure be made in the middle of the mouth by the tip of the tongue rising against the roof, the sound expressed by T is produced, and the syllable AT is heard; and so of others. It is to be remarked also, that the ear is equally sensible of the peculiarities, whether the closure precedes the continued sound or follows it: that is to say, whether the syllables pronounced are AP, AT, AK, or PA, TA, KA. The modifications of which we are now speaking appear, then, not to be really sounds, but only manners of beginning and ending sounds; and it is because they can thus be perceived only in connexion with vocal sounds that they are called consonants.

There are in the mouth, considered as a vocal tube, three situations in which interruptions of the voice or breath may most conveniently be made, and there are six modes of making it at each; so that eighteen distinct interruptive modifications or consonants hence arise. These we shall now describe.

The three great *oral positions*, as they may be called, are:—

1. At the external confine of the mouth, or lips, giving the *labial* articulations.

2. In the middle of the mouth, where the tip of the tongue approaches the palate, behind the teeth, producing the *palatal* articulations.

3. Near the back of the mouth, where the body of the tongue approaches the palate, giving the *guttural* articulations.

The *six modes* in which the voice or breath may be affected in passing through each of the three positions of the mouth are the following:—

1. A *sudden stoppage*, producing what may be called a *mute* articulation, viz. P in the labial position, T in the palatal, and K in the guttural. In pronouncing experimentally, it is better that the vowel be heard before the consonant than after it, as by sounding the syllable AB instead of BA. See the general Table of articulations on page 233. The Table may be considered as representing the tube of the mouth, with the letters so placed in it as to show in what situations they are severally produced. A mute may also be made by stopping the breath exactly at the teeth, producing thus a *dental mute*; but it is

hardly distinguishable from the *palatal mute* just behind it, and being less perfect, is not used. Some awkward speakers substitute it for the proper mute, and are said to speak thick. If the sides of the tongue be depressed after it has taken the position required for T, the sound L is produced.

2. A sudden shutting, as in the previous case, but the voice being allowed to continue until the part of the mouth behind the closures be distended with air. This produces the *semi-mutes* B, D, and G (in its hard sound, as in *pig*), for the three positions. There might be a dental *half-mute*, but it is of no more use than the *dental mute*, and for the same reasons.

3. The positions closed, as for the mutes, while sound is allowed to pass by the nose. Thus arise the *semi-vowels* or *nasals*, M, N, NG, for these three positions. NG (as in *king*) is a simple sound, although our imperfect alphabet has no single letter for it. The nasal sound of the French language, which gives it so great a peculiarity, approximates to the English NG, but differs from it in the sound passing by the mouth as well as by the nose. It is represented by *ng* in the Table.

4. Breath only, or whisper, allowed to pass at the three oral positions nearly closed. Hence come the sounds which we call *aspirates*, viz. F, TH, and CH; the two latter are simple sounds, although expressed in English by two letters. The TH is heard in the word bath, and is the ϑ of the Greeks. The CH is heard in the Scotch word *loch*, in the German *ich*, and is the χ of the Greeks. The *soft palatal aspirate* TH is not so easily made as the *dental*, which is heard on pressing the tongue gently against the teeth, and allowing the breath to pass all round; the *dental*, therefore, is used in preference to the *palatal*. The letter S is the *hard palatal aspirate*, and differs from the *soft aspirate* TH in the breath being made to issue with greater force, and only by a narrow space over the centre of a rigid tongue, instead of on all sides of a soft tongue, as for TH. French people, on first attempting to pronounce TH, always substitute for it the S or the Z (which is nearly related to S, as explained below). A little practice will enable them to pronounce the TH at once, and perfectly, by explaining its nature as above. If we depress the sides of the tongue while pronouncing S, we make the simple sound expressed by the English double letter SH; just as by

depressing the sides of the tongue while making T we produce L.

5. Using *voice* in the same manner as *breath*, or whisper, for the aspirates. This produces the sounds called *vocal aspirates*, is heard in *bathe*, as contrasted with the *simple aspirates* in *bath*: Z comes from the S position, only with *sound* instead of *breath*; SH pronounced with *voice* becomes the J of the French in the word *je*, or the sound heard in the middle of the English word *vision*. GH is a simple sound, used in German, but not in English.

6. Shaking the approaching parts in the three positions. We thus make *vibratory sounds*, of which the middle position gives the common R,—the only one of them used in England. Some bad speakers of English, however, make the *labial vibratory* by shaking the P in such words as *property*; and many use the *guttural*, which is the *burr* of Northumberland, and the common affectation in the Parisian speech called *parler gras*, or *grasseyer*.

TABLE OF ARTICULATIONS.

Labial.	Palatal.	Guttural.	
P	T, L	K	Mute.
B	D	G	Semimute.
M	N	ng, m	Semivowel or nasal.
F	th, s, sh	ch, H	Aspirate.
V	th, z, J	gh	Vocal aspirate.
pr	R	ghr	Vibratory.

Additional Remarks.

The sound of H does not belong to any of the three positions; and, indeed, is merely a forcible passing of the breath through the back part of the mouth or throat.

CH, in such words as *chain*, means T before SH.

J, as heard in the English word *John*, is a compound sound, viz. D before the simple J of the Table, which is S of *vision*.

LL. The liquid or double LL of the French, as heard in the word *paille*, is merely L with the letter Y begun to be pronounced after it. It is heard in the English word *billiard*

and *halyard*, and would be their terminating liquid were the syllable *ard* not pronounced.

GN. The soft GN of the Italians and French is the English N with Y begun to be pronounced after it. It is heard in our word *tan-yard*; and in the Italian words *pegno*, *bagnio*; and in the French word *craignent*.

C in English stands always either for S or K, as in the words *certain* and *car*, and has no sounds proper to itself.

Q expresses a compound sound, viz. of the letter K with U following it.

The consonants are best heard by sounding them with voice before them; that is to say, by making them rather terminate a syllable than begin it; pronouncing B, D, G thus, *eb*, *ed*, *eg*, rather than their common alphabetical names, *be*, *de*, *ge*.

The labial sounds may be made either by the two lips, or by one lip and opposite teeth.

F may be pronounced, for instance, by the lips only, or by the lips and teeth; and some persons awkwardly make it by the under teeth and upper lip.

The letters Y and I, in most modern languages, stand for nearly the same sound. In English, for instance, *bullion* and *minion* might be written *bullyon* and *minyon* without suggesting a change of pronunciation. In the words *yard*, *you*, *yes*, &c., the Y is a short I, very closely joined to the following syllable.—W is also thus a short U, as perceived in the words *war*, *we*, &c.

"By language fathers have communicated their gathered observations to their children; and these again, with gradual accumulations, to new descendants; and when, after many ages, the precious store had increased until the simple powers of memory could retain no more, the art of writing arose, making language visible and permanent, and enlarging without limits the receptacles of wisdom; and then the art of printing came, to roll the still swelling flood of knowledge into every hamlet and every hut. Language thus, at the present moment of the world's existence, may be said to bind the whole human race of uncounted millions into one gigantic rational being, whose memory reaches to the beginning of written record, and retains imperishably the important events that have occurred; whose judgment, analysing the treasures of memory, has already discovered many of the sublime and unchanging laws

of nature, and has built on them the arts of life, and through them, piercing far into futurity, sees distinctly events that are to come; and whose eyes and ears and observant mind, at this moment, in every corner of the earth, are watching and recording new phenomena, for the purpose of still better comprehending the magnificence and simplicity and beauty of creation."—*Dr. Arnott.*

CHAPTER VIII.

HEAT.

Nature of Heat.

Heat, as well as light and electricity, is called an *imponderable* agent, because, whether material or not, it is certain that it has no weight. A body which is *warm* (*i. e.* under the influence of heat) is neither heavier nor lighter than one which is *cold*. Heat is also called *caloric*. Like light, it is capable of being radiated from a centre, of being reflected in straight lines from certain surfaces, and transmitted by certain media. It differs from light in its power of entering into combination with material bodies. It causes them to become *warm* or *hot* to the sense of touch, in various degrees, according to the amount of *heat* present. At the same time it increases the distance between the particles of the body, causing them to repel each other, or, as some have supposed, insinuating itself between them, and actually itself occupying space. Not only does heat separate the molecules of a body, and thus cause it to occupy a greater space than before, but it loosens their mutual adhesion, so that under this influence a solid becomes a liquid, and a liquid becomes a vapour or a gas. It also promotes chemical change. It may cause the combination of elements that are apt to combine, as when the carbon of wood combines with the oxygen of the air, the wood, by the removal of this carbon, being *burnt* or destroyed; or it may simply separate elements previously united, as when the oxygen is driven off by heat from the oxide of a metal.

Light affects only the sense of vision. Heat acts on the sense of touch or feeling, causing to the skin a sensation of warmth or burning.

Heat may therefore be defined as follows:—an agency (or

matter) that produces expansion, weakens cohesion, promotes chemical change, and is recognized by the sense of feeling.

On attempting to go further, we find ourselves at a standstill. What is heat? And first, is it material or immaterial? Its being so potent a cause of expansion, has led to the belief that it is a *material* agent of extreme tenuity, possessed of indefinite powers of self-repulsion, so that it pushes asunder the particles of a body just in proportion to the degree in which it exists in that body. It exists to some extent in all substances, and may be eliminated or, as it were, squeezed out of them by friction or compression. The savage inflames two dry sticks by rubbing them together, and Count Rumford caused water to boil by boring metal beneath its surface. Heat becomes combined with matter, and differs thus essentially from light, which ceases to be evident when the radiating source is cut off. Light, when absorbed, is lost; heat, when absorbed, continues active. Heat is generally known in combination with matter; yet, like light, it radiates through a vacuum, and must therefore have an independent existence.

The arguments against the materiality of heat are stronger than those in its favour. It is imponderable. It is transmitted by radiation, in the manner of forces, and of light, an influence having the nature of a force. It is very frequently accompanied by light, as in the heat of the sun, ordinary combustion, and the electric spark; and light is now generally supposed to be immaterial. Like light, it is reflected only by certain surfaces, and transmitted only by certain media. Light is conceived to consist of *lines of rapid vibration in the particles of an imponderable fluid* (*or* "*æther*") *which pervades all space.* Heat may thus consist of another kind of vibrations in the same particles. If so, these vibrations must be of such a nature as to cause the particles of matter to fly asunder, producing repulsion. Besides this, they must be permanent vibrations, motions which never cease. Heat remains combined with matter, and light ceases when a ray is cut off. A sonorous body cannot resound for ever of its own accord, but the heat vibrations in all bodies must continue without limit until transferred by contact with another body, or by radiation. All heated matters lose heat by conduction (contact) or radiation, until an equilibrium of temperature is obtained. Hot water in an apartment cools gradually to the temperature of

the room. The earth at night loses much of the heat it has absorbed by day, by radiation into the cooler atmosphere. This cooling may go on at the pole till the earth has fallen to the temperature of the planetary space. The hand laid on marble or cold steel, at once loses heat by conduction,—it feels *cold*. Cold is the comparative absence of heat. Heat is never absolutely absent from anything. There is no known limit to the degree of cold which may be produced. The feeling of warmth is the communication of heat to the skin from a substance warmer than itself. Either heat or cold, beyond a certain point, would cause destruction of tissue and of life,—heat, by burning and decomposing; cold, by contracting or freezing.

The transference of heat from one body to another is caused simply by a general tendency to an equilibrium, or identity of temperature in all matter; but no substance ever cools down to such a point as to be entirely devoid of heat.

Heat is thus a radiating force which resembles light in many respects, but differs from it in its permanency, or power of combining with matter. The theory of heat which we have ventured thus dubiously to announce, was carried out in a more positive manner by the illustrious Sir Humphry Davy, who attributed the permanence of heat to the existence of heat-vibrations in the solid particles of matter itself. He remarks, "The immediate cause of the phenomena of heat is motion; and the laws of its communication are precisely the same as the laws of the communication of motion. Since all matter may be made to fill a smaller volume by cooling, it is evident that the particles of matter must have space between them; and since every body can communicate the power of expansion to a body of a lower temperature, that is, can give an expansive motion to its particles, it is a probable inference that its own particles are possessed of a motion; but as there is no change in the position of its parts as long as its temperature is uniform, the motion, if it exists, must be a vibratory or undulatory motion, or a motion of particles round their axes, or a motion of particles round each other. Again, it seems possible to account for all the phenomena of heat, if it be supposed that in solids the particles are in a state of vibratory motion, the particles of the hottest moving with the greatest velocity, and through the greatest space; that in liquids and elastic fluids,

besides the vibratory motion, which must be conceived greatest in the last, the particles have a motion round their own axes, with different velocities, and separate from each other, penetrating through right lines. Temperature may be conceived to depend upon the velocities of the vibrations, increase of capacity on the motion being performed in greater space; and the diminution of temperature during the conversion of solids into fluids or gases may be explained on the idea of the loss of vibratory motion, in consequence of the revolution of particles round their axes, at the moment when the body becomes liquid or uniform; or from the loss of rapidity of vibration in consequence of the motion of the particles through greater space." It must be observed that Locke, before Davy, considered heat to be a "motion or brisk agitation of the insensible parts of an object."

That heat, though so often connected with light, is not a mere variety of the same force, seems to have been proved by Melloni, who has effected a distinct separation between them. A plate of obsidian or black mica allows heat to pass freely through it, but scarcely any light; whereas a peculiar kind of green glass, brushed on one side with a solution of alum, permits the passage of light, but not of heat. By certain coloured solutions, similar results may be obtained.

Sources of Heat.

The sun is the great source of heat. Heat reaches us from the sun by radiation with the same rapidity as light, which it accompanies. The earth, when removed more or less from the sun's influence, as in winter or at the Pole, becomes cold, and loses its own heat by radiation into space. When the ray of light in the sunbeam is decomposed by the prism into its component parts, it is found that the greatest degree of heat coincides with the red ray, and extends beyond it, the ray of heat transcending considerably the limits of the ray of light.

The earth itself is a second source of heat. The great interior mass of our planet is believed to be in a state of fiery ignition, consisting of a liquid mass of molten rock such as is occasionally ejected from the mouths of volcanoes. However, the solid crust of the earth, which is many miles in thickness, is so bad a conductor of heat, as to prevent this high temperature of the interior from producing much effect at the surface

Friction and *compression* are a cause of heat. When the particles of matter are brought into closer contact, heat is eliminated from them. When they are separated or expanded, heat is absorbed from surrounding bodies. Compressed air gives out great heat; on being again allowed to expand, it produces cold (*i. e.* absorbs heat). Pieces of wood, rubbed together, may burn, from the compression of the superficial particles. A metal button, rubbed briskly on a piece of cloth, becomes soon too hot to be held. Count Rumford caused water to boil by the friction produced in boring a brass cannon. A coin just struck with the die is intensely hot. A heated piece of iron may be hammered up to a white heat by the blacksmith. Heat in all these cases results from compression.

Chemical action is a source of heat. The artificial heat which protects us from the cold of winter is derived from combustion. Combustion is simply the rapid oxidation (combination with the oxygen of air) of the carbon and hydrogen which exist in organic bodies. Combustion gives out light as well as heat. A body may be heated to a considerable extent without evolving light, but heat is usually accompanied by light as soon as the substance has reached the temperature of about 1000° of Fahrenheit's thermometer. When this evolution of heat and light is accompanied by oxidation, the process is called *combustion*. When there is no oxidation, it is called *ignition*, as seen in iron at a white heat.

Any chemical combination which produces condensation, will also cause heat. A familiar example of this occurs when oil of vitriol is mixed with water, the two liquids when together occupying a smaller space than they did when separate.

Electric action is another source of heat. When an electric current suddenly overcomes an obstacle, as passing from one conductor to another through the air, heat and light are developed in the electric spark; or when it passes through a conducting medium which offers much resistance to its passage, heat may be produced, as seen in the incandescence of a thin platinum wire, which may even be melted by the current of a powerful battery. By causing the current to pass between charcoal points terminating the wires of a galvanic battery, the electric light is produced. By the spark of a discharge, such heat is procured as will suffice to ignite gunpowder, to explode a mine under the earth, or under water. Thus under

certain circumstances, electricity produces heat; under certain others, heat will produce electricity; there must therefore be some analogy between these agencies, as well as between heat and light.

Vital action is sometimes enumerated as a cause of heat. It is probable, however, that all the heat of the animal frame depends on the continual *combustion* in a slow manner of certain elements of the food by means of oxygen received into the system from the air inhaled in the process of respiration. Some suppose that heat is evolved by nervous (as well as by electrical action. The human body and that of quadrupeds is maintained continually at the temperature of 98°—100°. The body of a bird may be at 120°.

There is a mutual relation between heat and life. Heat causes life, and life produces heat. Without a certain temperature, seeds do not germinate, eggs are not hatched, plants and animals die. Animals manufacture their own heat. Plants cannot do this, they depend on the world around them; in winter they perish or are dormant. The returning heat of spring, recalling them to life, clothes the woods, and fills the fields with plenty. Heat is employed by man for his own purposes; it produces expansion, and is his great source of motion and power. It renders metals tractable, so that he moulds and works them to his will; by its agency hard organized substances are softened, and rendered fit for human food. In the absence of heat, all is sterility, solidity, and silence; nature ceases from her works, and slumbers in a sleep as of death.

Expansion caused by Heat.

Heat is the direct antagonist of the cohesive force in matter. It causes the particles to separate, so that the body which consists of them is both rendered less firm and coherent, and occupies a greater space. If not decomposed, a solid is transformed by heat into a liquid, and the liquid, at a still higher temperature, becomes a gas or vapour. But even without this change in its essential form, the substance heated undergoes expansion. A closed bladder will burst if heated, by the expansion of the air within it. The expansive force of the vapour of water is well known. Liquids expand as well as gases. If a narrow tube be fitted to a flask full of water, and heat be applied to

the flask, the water will gradually rise in the tube. The gradual expansion by heat of the fluid metal mercury supplies us with that valuable instrument, the mercurial *thermometer*. Thermometers may also be made of air or water, both of which expand pretty equally for equal increments of heat. If heated from the temperature of ice to that at which water boils, 1000 parts of mercury measure 1018 parts, of water 1045, of oil 1095, and of alcohol 1100. Here the lightest and least coherent liquids expand the most.

Solids likewise expand with heat. In those which easily melt, in compressible materials, and in substances like wood, which are decomposed by a high temperature, this increase in bulk is not easily measured. But in metals, which are firm, and bear a high heat without fusing, it is readily appreciated.

The expansion of iron by heat is demonstrated in a very simple manner: *c a b* (fig. 157) is a gauge into which the piece of iron *a* fixed to a handle, when cold, fits easily into the part cut out at the edge; but when *a* is heated, from its then expanded state, it will not pass into the open part; *f* is a circular rod of iron, and freely passes into the holes *b c* when cold; but on being heated, it is found then to be too large for the holes.

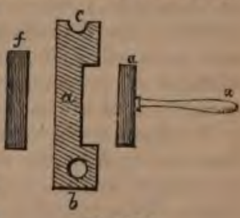


Fig. 157.

Heated to the same extent as above mentioned, the following metals expand in different degrees, to which the ratio subjoined will be an approximate guide:—

Copper . . .	$\frac{1}{581}$ of its length.
Iron . . .	$\frac{1}{819}$ "
Lead . . .	$\frac{1}{351}$ "
Tin . . .	$\frac{1}{462}$ "
Silver . . .	$\frac{1}{524}$ "
Gold . . .	$\frac{1}{682}$ "
Platinum . . .	$\frac{1}{1167}$ "

Taking advantage of the knowledge obtained by the investigations which have been very carefully made into the laws of expansion in bars of metals, we have been enabled to give a constancy to the lengths of the pendulum; every variation in the length of which produces a corresponding variation in its rate of oscillation. *Compensation pendulums*, as they are called, are variously made; the most common form being the

gridiron pendulum. In this, the main rod is of iron, and the inner ones of zinc or brass. As the expansion of zinc exceeds that of iron, the bars are made unequal; and such a relation is established between them, that the elevation of one exactly counterbalances the depression of the other. The *mercurial compensation pendulum* is another form, in which the same kind of compensation is effected by means of fluid mercury and iron.

The expansion and contraction of iron is exemplified in Hungerford Suspension Bridge, which crosses the Thames with a span of 1352 feet in length; the height of this chain roadway varies in the hottest day of summer and the coldest in winter to the extent of eight inches. Due allowance has been made, in laying down railroads, for the expansion and contraction of the iron rails. The steeple of the first Bow Church, in Cheapside, London, was fastened together with iron by the architect, and the consequence was, that the alternate expansion and contraction of the iron-work which took place from the changes of temperature of the atmosphere, so loosened the masonry that the bells were for many years silent.

We know from every-day experience the effect produced by heat and cold on the strings of a pianoforte, the iron gates of a mansion, and the bell-wires of a house; we hear too, sometimes, of the iron girders and pillars used in buildings bringing down the entire fabric by their change of length.

Other familiar phenomena are due to the expansion caused by heat. Doors and windows that fitted loosely in the winter, may become tight in the summer. A thick glass vessel will break when hot water is poured into it, as, the glass being a bad conductor of heat, the inner layer expands before the outer has had time to do so. A thin glass will escape, as it is heated through immediately.

Of crystals, when heated, it is remarkable that they frequently expand in one direction (that of one of their axes) more than in another. Water presents us with an extraordinary exception to the usual effects of heat and cold. Nearly down to the freezing-point it goes on regularly contracting, but on becoming ice it expands, and occupies more space than when in the liquid form. Ice, when first melted by heat, does not expand, but positively contracts. It constitutes a most important exception to a rule that is almost universal.

The same power by which it separates and drives asunder the atoms of simple bodies, causes heat to be a powerful agent in promoting chemical decomposition. This has already been instanced in the *burning* of organic substances. Most mineral or inorganic compounds are in the same manner decomposed by heat, though they require a higher temperature for the purpose. Even water, which is converted by heat into steam, may be decomposed into its two gaseous elements by an intense heat instantaneously brought into action. This has been shown by some recent experiments of Mr. Grove. If platinum wire be fused by the blowpipe and the globule allowed to fall into water, bubbles of oxygen and hydrogen form together with steam, and may be collected in a glass tube as they rise. The same effect is produced by the electric spark, or by a fine piece of platinum wire connected at each end with one pole of a battery, so as to become incandescent.

The most simple form of the experiment is as follows: A tube (of the form of Volta's eudiometer, having a curved piece of platinum wire soldered into it above) being filled with water, is placed in an inclined position, and the flame of a spirit-lamp made to play upon its upper part, until a portion of it is converted into steam; contact is then made between the battery and the wire; and, as the wire becomes instantly white hot, the decomposition is effected, and a bubble of mixed gas formed. This bubble appears to be formed by the first action; for, however long the operation may be continued with the same steam, no further decomposition results: remove the lamp, and allow the water again to fill the tube, and again convert some of it into steam, and another bubble may be formed. The experiment was tried under a different form, and the same result produced by the electrical spark, to the heat of which alone Mr. Grove thinks the decomposition of the water is due.

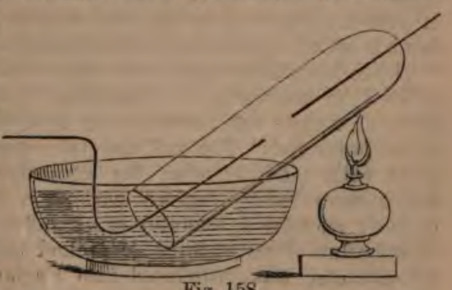


Fig. 158.

INSTRUMENTS TO MEASURE HEAT.

any [illegible] particular temperature [illegible], will always undergo the same amount of expansion. If a certain increment of heat cause it at one time to change in bulk to the extent of ——th part, the same increment will change it to the same extent at any other time. Depending on this uniformity of effect, we obtain in the expansion of a body a simple mode of measuring heat. In measuring a moderate degree of heat, we make use of a liquid which expands with readiness, and can be easily measured. Such a liquid enclosed in the proper apparatus for measuring it forms the instrument called *thermometer*, or heat-measurer.

To measure a high degree of heat, as that of a furnace, we cannot employ a liquid which would be at once dissipated into vapour; we must use a solid which has a great power of withstanding heat, as [illegible] of platinum. Such an instrument is called a pyrometer, or fire-measurer.

The earliest thermometer was constructed towards the middle of the 17th century by the Florentine academicians. It consisted of a glass tube terminating in a bulb or hollow ball at the lower end. The ball and tube were filled to a certain point with spirit, the expansion or contraction of which, measured by degrees marked on the tube with white enamel, afforded a correct indication of the changes in temperature of the atmosphere around the bulb. This spirit thermometer was introduced into England by Boyle. The glass tube may be sealed at the upper end, and the air confined submits to compression when the fluid expands.

Take a similar tube, with the end unsealed, and when full of air only, plunge the open end downwards into some coloured liquid, and an *air thermometer* is formed. The whole being fixed in this position, a scale is adjusted behind the tube. The expansion of the air in the bulb and tube will drive out the liquid in warm weather, and in cold weather its contraction will draw the coloured water to a certain height up the tube. As the air readily expands, this instrument is very sensitive; but it is not very accurate, and can only be employed to indicate slight variations in temperature. The chief cause of error is the varying pressure of the atmosphere on the surface of the

fluid in the vessel below. In *Leslie's differential thermometer* this disturbing influence is excluded. This, however, can only be used for a special purpose. Two bulbs and tubes are arranged parallel to one another, and the tubes connected by a cross one below, which is fixed to a stand. The cross tube and about half of each of the vertical tubes, are filled with the coloured water. The amount of air is the same on each side. If both bulbs are at the same heat, the liquid is at the same height in the tubes. If one be warmer than the other, the air expands, and presses the liquid towards the other bulb. Thus the liquid indicates only *any difference in temperature* between the two bulbs, and the instrument is employed in certain delicate experiments to be mentioned presently.

Fahrenheit, the Dane, about the commencement of the 18th century, introduced mercury as a means of measuring heat; and as this liquid metal expands moderately but uniformly for equal increments of heat, a great improvement was effected by its use. In the first *mercurial thermometers* constructed, a great want was perceived of some fixed points from which to start in their graduation. Hooke and Newton discovered these fixed points in the freezing- and boiling-points of water. The exact degree to which the mercury contracted when the bulb of the thermometer was kept for some time in melting ice or freezing water (which are of the same temperature), formed a point from which to start below. The degree to which it expanded when plunged in boiling water, formed another fixed point above. The space along the tube between these two points was divided by Fahrenheit into 180 degrees. But he did not make the freezing-point his zero—he went lower. Salt mixed with snow or ice sinks to a certain very low temperature, which is found to be invariably the same. This is the zero of Fahrenheit's thermometer. The space between this and the freezing-point of water is found to measure 32 of the same degrees as those marked off between the freezing- and boiling-points; the freezing-point is thus marked 32°; add 180° for the boiling-point, and we have 212°. Between these there are frequently marked on the scale other points more or less arbitrary. At 56°, temperate heat; 76°, summer heat; 98°, blood heat; 112°, fever heat. The mercurial thermometer may be further graduated so as to measure degrees of heat above

the boiling-point of water, as high as 600°, or to the boiling-point of mercury.

It is a matter to be much regretted that different thermometric scales are in use in different countries. The thermometer of Reaumur, that called Centigrade, and that of De Lisle, are all used on the Continent. Reaumur commences his scale at 0, which he makes the freezing-point, and divides up to boiling-point into 80 equal parts. The Swedish thermometer, called the Centigrade, divides the space between the two points into 100 exact parts or degrees. As sometimes the one scale and sometimes the other is given, it is well to know how to compare them with that with which we are best acquainted; therefore to change Fahrenheit's into Reaumur's scale, multiply the number of degrees above or below 32 by 4, and divide by 9. To change Reaumur's into Fahrenheit's scale, multiply the degree by 9, divide by 4, and add 32. To change Fahrenheit into the Centigrade, multiply the degrees above or below 32 degrees by 5, and divide by 9. To change the Centigrade into Fahrenheit, multiply by 9, divide by 5, and add 32.

England, Holland, and North America adopt Fahrenheit's scale; Sweden, Celsius's Centigrade; and France and Germany, Reaumur's or the Centigrade scales. Fig. 159 shows the three scales of the thermometer.

The utmost extent of the mercurial thermometer is within the points at which quicksilver boils and freezes; that is, as high as 600 and as low as 40° below 0; consequently the thermometer in extent can range 640°.

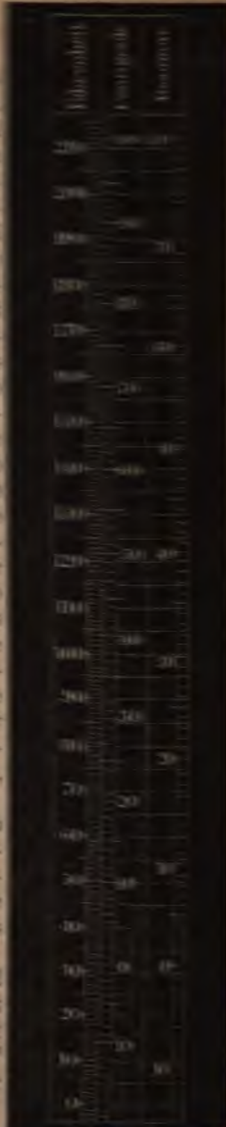


Fig. 159.

In constructing a thermometer, it is necessary to seal the upper end of the tube; but, before doing this, the air contained in it above must be completely expelled, else its contractions and expansions would materially interfere with the indications derived from the mercury. The instrument is made in the following manner:—A tube of glass being procured, having a very regular but extremely small bore, one end is blown out to a bulb, the diameter of which is made large comparatively to the diameter of the tube. The bulb and stem is then heated to expand the air within it, after which the open end is quickly plunged into a basin of mercury. The glass then being permitted to cool, the internal air contracts, and the atmosphere pressing on the surface of the mercury in the basin, a little of it is forced up the tube. A small quantity of mercury being thus got into the bulb, the mercury is then boiled in the bulb, which expels all atmospheric air and thoroughly dries the tube. The open end is plunged again into the basin of mercury, and on cooling more mercury enters and quite fills the thermometer. The open end is then drawn into a fine capillary tube, the mercury in the tube and stem being slightly heated; as it cools, the tube is finally sealed by fusing with a blowpipe the open end, and the thermometer is so far finished as to be ready for graduating.

To mark the freezing-point, thermometers are first placed upright in pure melting snow or ice; the fluid in the tube contracts and takes up a settled position, to which on every immersion it returns, from the temperature being always the same; but if marked immediately, and some months afterwards again tested, it will be found from one-half to two degrees above the first mark. This is supposed to arise from the contraction of the bulb, which is gradually brought about from the constant pressure of the atmosphere; hence twelve months should be allowed to elapse before the mark is permanently decided upon. The boiling-point is found by laying the thermometer in the steam just above the surface of distilled boiling water, the barometer standing at 30 inches, until the mercury becomes stationary; were it dipped in, as the heat decreases with the depth, it would not be accurate.

For all ordinary purposes the mercurial thermometer is found to answer well; but we may be asked, if solids are also affected by changes of temperature, must not the glass of

which the thermometer is formed also vary? This certainly is the case; but so slightly as to give a degree of accuracy to be found with no other transparent body with which we are acquainted.

Mercury, possessing a uniformity of expansion, is found the best material to indicate the variations of temperature by any change in its volume, and being also a good conductor of heat, is constantly used for thermometers.

When very intense degrees of cold have to be ascertained, as mercury freezes at 40 degrees below the zero of Fahrenheit, spirit of wine coloured red is used, as it does not freeze until a cold 68 degrees below zero exists. This fluid, however, would not do to measure heat, as it boils at 172 degrees, which is considerably less than the boiling-point of water, 212 degrees. To determine very high temperatures, as mercury boils at 680 degrees, various methods are adopted, all of which, however, are difficult of management.

Before speaking of these, we have to notice some modifications of the thermometer required for special purposes.

In a course of systematic observations of the temperature of any district, or season of the year, it is desirable to ascertain, with as much certainty and as little trouble as possible, the highest and lowest points to which the mercury rises by day or sinks by night. To save the necessity of constant personal observation, an instrument is constructed that *will register itself*.

Rutherford's thermometer consists of two instruments placed horizontally, the one a mercurial, the other a spirit thermometer (fig. 160). The upper registers the *maximum*, the lower the *minimum* temperature that has occurred between two observations. At the end of the mercurial column is a small steel pin, which is pushed forwards by the mercury when expanding, but left alone when it recedes. The end of this pin indicates the maximum heat. In the spirit is placed a fine piece of enamel or dark glass, heavier than the liquid in which it is immersed. The spirit goes on contracting even at an extreme degree of cold. As it contracts it draws along with it the enamel pin, by the force of adhesion. But as it expands again, it readily passes by

Fig. 160.

the enamel, which is left to indicate the minimum temperature, or extreme degree of cold. An adjustment is requisite to prepare the instrument for the next observation. The steel pin is drawn back to the mercurial column by means of a small magnet moved along the glass outside. The enamel pin falls to the end of the spirit column on slightly inclining the instrument.

Six's thermometer combines both arrangements in the same tube, bent twice (fig. 161). The bulb is in the form of a long cylinder, which is filled with spirit of wine, and in contact with a portion of mercury, occupying the lower part of the tube; this is succeeded in the second bend, by a second portion of spirit, above which is a bulb containing air. The mercury carries on each of its surfaces an index, which is retained in its remotest situation by means of a weak spring. By the expansion or contraction of the spirit in the long bulb, the mercury is pushed onwards or drawn backwards, and in one or the other arm are thus marked, by the steel index, the extremes of heat and cold.

Fig. 161.

This instrument is not to be depended on where great accuracy is required; the spirit does not expand quite equally for equal increments of heat; and the expansions and contractions of the mercury and of the small quantity of air in the second bulb, operate as disturbing causes. The index in this instrument and in Rutherford's is liable to corrode, or to become fixed from other causes; then the instrument will of course not act.

Maximum thermometers of greater accuracy have been invented, but great care is required in the making. Messrs. Negretti and Zambra have made an instrument in which

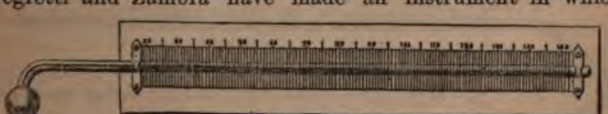


Fig. 162.—Negretti and Zambra's Maximum Thermometer.

the steel index is dispensed with. A small piece of glass is inserted within the tube, past which the mercury is forced in

its expansion, but cannot repass in its contraction. The end of the column, therefore, gives the required reading, as the contraction of the mercury takes place within the space below the bend of the tube. This instrument is easily set, and is scarcely liable to derangement (fig. 162).

A still simpler instrument has been constructed by the same makers,—an ordinary thermometer, placed likewise horizontally, with a contraction in the tube just beyond the bulb. Through this the mercury passes on expanding, but cannot repass on contracting. The end of the column in the tube (which should be of very fine bore) gives the maximum temperature. The instrument is adjusted by placing it vertically and with a slight swinging or jerking motion, restoring the contact of the mercury in the tube with that in the bulb.

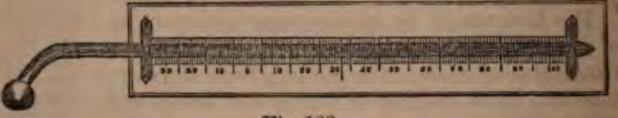


Fig. 163.

The separate minimum instrument is a spirit thermometer with an index floating in the alcohol, drawn by it in retiring, but passed in expanding. As the alcohol does not expand regularly, the tube is not of even bore. This instrument is not fitted for delicate observations.

Thermometers for observing the variations of heat depending on the relative amount of *solar* and *terrestrial radiation*, require very great nicety in their construction. We represent two instruments made for this purpose by Messrs. Negretti and Zambra.

The maximum thermometer for solar radiation (fig. 164) is an extremely delicate mercurial glass thermometer, with black-

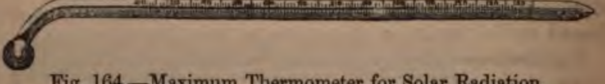


Fig. 164.—Maximum Thermometer for Solar Radiation.

ened bulb, and graduated on its own stem; it is furnished with a steel index similar to that of the maximum thermometer of Rutherford.

This instrument should be so placed that its bulb is fully

exposed to the sun, but at the same time guarded from any strong draughts or currents of air.

The corresponding minimum instrument is for the determination of the lowest temperature of the earth, on which it

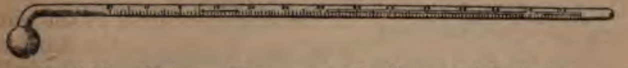


Fig. 165.—Minimum Thermometer for Terrestrial Radiation.

should be placed, resting on grass, its bulb fully exposed to the sky. This instrument is likewise graduated on its own stem; its bulb is transparent, and it is filled with alcohol (fig. 165).

The double thermometer, one of the ordinary construction, the other with its bulb kept wet, is used to indicate the dew-point, and is called *the wet and dry bulb thermometer*.

The instrument, as made by Negretti and Zambra, consists of two extremely delicate and similar thermometers, suspended side by side, and braced together by a cross piece of metal, upon which they are adjusted by means of screws and steadying-pins.

The two thermometers should be uniform in size. One has its bulb uncovered, and is termed the dry bulb; the other is enveloped with fine muslin, from which a piece of darning cotton or lamp-wick proceeds to a glass beaker, or cup of water placed contiguous to the bulb (fig. 166).

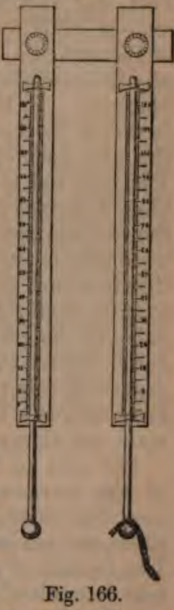


Fig. 166.

The instrument thus fitted is ready for use; it should be placed out of doors in the shade, and suspended with the bulbs about four feet from the ground. Care should be taken that the water-vessel be at all times supplied with water, and the conducting thread and muslin occasionally renewed.

The readings of the instrument should be taken at definite times, and signify as follows:—

That of the wet bulb, as moistened by the water passing up the conducting thread, is cooled by evaporation, and as this is greater in proportion as

the air is deficient in aqueous vapour, it gives a reading depending upon the amount of water then mixed with the air in the invisible shape. When the air is saturated, this reading is the same as that of the dry-bulb thermometer; when the air is not saturated, it reads less than the dry bulb; and when the air is very dry, the difference between the readings of the two instruments is great.

From the joint reading of the two thermometers, the actual amount of water then present in the air, as well as the degree of humidity, can be readily determined; and, when further combined with the reading of the barometer, the actual weight of any mass of air, in its then state of temperature, pressure, and humidity, becomes known.

Instruments called Pyrometers are used to measure very high temperatures. Wedgwood's consists of a cylindrical piece of porcelain clay, which *contracts* with the increase of heat, and thus marks the degree: the zero of Wedgwood's scale is 1077°·5 of Fahrenheit, and each degree equal to 130° of Fahrenheit's. Pyrometers of modern construction act usually in consequence of the expansion of that infusible metal, platinum. In Daniell's pyrometer the change of temperature is shown by the excess of the expansion of an iron bar over the expansion of a black-lead case, in which it is enclosed. The iron rod is shorter than the black-leadware case, and a plug of earthenware, which fits tight in the case, abuts against the iron rod inside. By the expansion of the iron the earthenware plug is pushed out, and it is held so tight in the case, that it cannot go back again when the apparatus cools; the protrusion of the earthenware plug is therefore a permanent index of the greatest amount of expansion that had been produced whilst the instrument was exposed to heat. This expansion being very small, the earthenware plug is made to press against a lever, which moves an index over a graduated scale, and thus measures the degree with accuracy.

The scale of this pyrometer is readily connected with that of the thermometer by immersing the register in boiling mercury, whose temperature is as constant as that of boiling water, and has been accurately determined by the thermometer. The amount of expansion for a known number of degrees is thus determined, and the value of all other expansions may be considered as proportional.

1 represents the register (fig. 167): A is a bar of black-

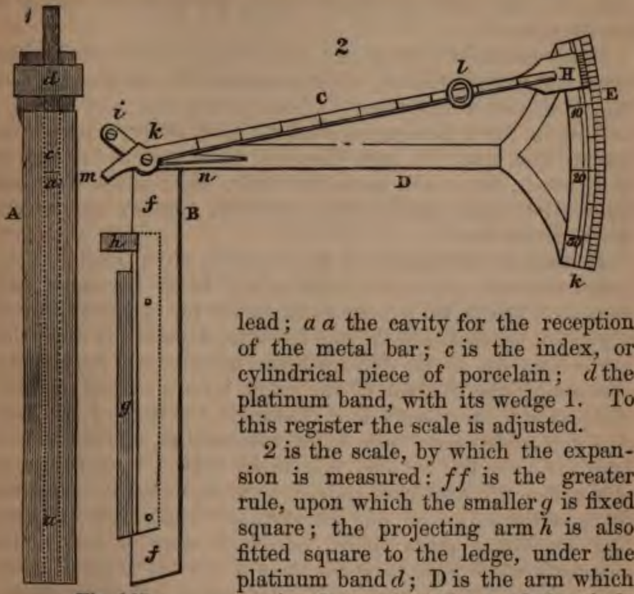


Fig. 167.

lead; *a a* the cavity for the reception of the metal bar; *c* is the index, or cylindrical piece of porcelain; *d* the platinum band, with its wedge 1. To this register the scale is adjusted.

2 is the scale, by which the expansion is measured: *f f* is the greater rule, upon which the smaller *g* is fixed square; the projecting arm *h* is also fitted square to the ledge, under the platinum band *d*; D is the arm which carries the graduated arc of the circle fixed to the rule *f f*, and moveable upon the centre *i*; C is the lighter bar fixed to the first, and moving upon the centre *k*; H is the nonius at one of its extremities, and *m* the steel point at the other. The rule *g* admits of adjustment upon *f f*, so that the arm *h* may be adjusted at the centre *i*, in order that at the commencement of an experiment the nonius may rest at the beginning of the scale.

Conduction of Heat.

The term *conduction* expresses the diffusion of heat through a solid body. Did heat not spread slowly through the entire mass, even the poker could not be used to stir the fire without burning the hand that uses it.

That heat travels at different speeds through the structure

of various substances is well known in the common experience of a teapot with a metal handle, and another with a wooden, bone, or ivory one, the former being hot when the latter is hardly warm.

Count Rumford made many interesting experiments on different substances, that he might ascertain the different degrees they possessed of the property of conducting heat, and they are ranked in the following succession: gold, silver, copper, platinum, iron, zinc, tin, lead, diamond, glass, marble, porcelain, clay, woods, fat or oil, snow, air, silk, wood-ashes, charcoal, lint, cotton, lamp-black, wool, raw silk, beaver's fur, eider-down, hare's fur.

If some article made of fur be lying on a marble table, both under the same circumstances will be of the same temperature; but if we lay one hand on the fur and the other on the table, we shall say the one is warm, the other is cold: this arises from the marble being a better conductor of heat, which abstracting the warmth of the hand, gives a feeling of cold; whereas the fur being a slow conductor, the heat of the hand does not readily pass into it, but accumulates, and warmth is felt. If both the fur and marble be heated, then the hand would feel the heat pass rapidly from the marble, while the fur would scarcely feel any warmer than usual. Count Rumford considered gases almost non-conductors of heat, most especially when their particles are not allowed to move about, as is exemplified in sponge and other porous bodies containing a quantity of air.

In the foregoing list it will be seen how wonderfully nature provides for the preservation of animal bodies. The ostrich has light thin feathers, as it needs only a spare clothing, while the sea-fowls have thick strong feathers and down to bear the rigours of the ocean's cold; the elephant has a few straggling hairs, while the arctic bear has a rough, thick, shaggy coat. The warm-blooded milk-giving whale is encased with fat to preserve its heat; and in trees and plants the bark is a substance that is a slow conductor of heat, so that vegetable warmth is preserved without injury. Thus is every thing adapted by a superior wisdom to the circumstances of its nature.

The boilers of steam-engines are encased in materials to prevent the escape of heat by having a slowly-conducting covering exposed to the atmosphere; and in winter people

wrap stable-straw around their water-pipes to prevent the escape of heat.

In the ice-shops of London, huge lumps may be seen wrapped in flannel, by which the greater heat of the atmosphere is prevented penetrating; the chests sold for its summer preservation are made double, and the interstices filled with sawdust or fine charcoal. Man wraps himself in woollen cloths in winter, not because there is warmth in the wool itself, but that it is a slow conductor of heat, and therefore retains the natural warmth of the human body.

Among domestic utensils many are joined with solder. Now it is seen in the manufacture of them, that solder is rendered fluid by no very great heat; yet when exposed to an intense fire it does not melt, because the heat passes into the water, which never can be heated beyond 212 degrees; but if this material that conducts the heat away be dried up, then the solder melts. Liquids and gases are much worse conductors than solids. A very simple experiment may afford a rough estimate of the comparative powers of conduction in the three classes of solid, liquid, and gaseous bodies. Metals heated to 120 degrees will severely burn a hand placed upon them, owing to the facility with which the heat will travel towards it; water will not scald, provided the hand be kept without motion in it, till it reaches the temperature of 150 degrees, while the contact of air may be endured at 300 degrees. Sir Joseph Banks ventured into a room heated to 260 degrees, and remained there a considerable time without inconvenience; and in several processes of the arts it is necessary for workmen to enter stoves heated as high as 300 degrees, from which no injurious effects follow.

To exemplify the difference between metal and glass in their powers of conducting heat, a simple experiment is exhibited. A piece of metal *b* and a piece of glass *d* of equal size and length are bound together at *c* with wire, and placed over a spirit-lamp *a*; and a piece of wax being placed on each of the other ends, that on the end of the metal *b* will be melted, while that on the glass *d* will not be softened.

Fig. 168.

From the difference of the conducting powers of heat in

various bodies, we find brass cannon become hot sooner than iron; water will boil in a metal pan quicker than an earthenware pipkin; and emigrants to hot countries find a log hut and a thatched roof cooler in summer and warmer in winter than a brick or stone mansion. Snow being a bad conductor of heat, the inhabitants of the arctic regions build their huts of it for their winter residence.

There are other modes of exhibiting the results shown in fig. 168: as, for instance, placing a series of short flat bars of different metals of equal thickness and width on a circular piece of wood like the horizon of a globe, having the points all meeting in a centre, underneath which is a spirit-lamp, the flame equally touching the points; near and on the further ends is placed a very small piece of phosphorus. When the heat begins to act on the metals, the phosphorus on the gold first flashes into flame and smoke; and nearly at the same time, but still not till after the gold, that on the silver; after a short space that on the copper, then follows the platinum, after that the iron, and then the lead. Or small pieces of wire of different metals may be fixed at one end into a slip of wood and tipped with candle-wax, and the other ends of the wire placed in a trough of heated water at exactly the same depths; the wax is seen to melt first on the silver, gold, and then at short intervals on the other metals.

Again, the ends of the wire may be made to protrude through the wood, and a marble fixed by wax on the other end; this last end is placed so as to hang over a table or box, and a heated bar of iron being brought against the short end projecting through the wood, first the marble attached to the silver wire drops, then that to the gold, followed by that on the copper, platinum, iron, and lead.

If in the experiments with the phosphorus and marble a piece of glass were used along with the metals, the phosphorus would not fire, nor would the marble drop, as before the heat could arrive at the ends, the bar of iron would become cold.

By breaking the cohesion of solids, their conducting power may be very much decreased; and on this account, by placing a layer of sand upon the hand, and carefully screening the surrounding parts, a red-hot ball of iron may be supported without inconvenience. At the siege of Gibraltar, red-hot

balls were carried to the batteries in wooden wheelbarrows, merely protected with a covering of sand.

Convection of Heat.

Liquids are bad conductors of heat. When any strata of fluids, whether liquid or gaseous, are heated, they become by expansion relatively lighter than those around them. Count Rumford's experiments led him to believe that there could be no change of temperature in liquids without a displacement of their particles, which is called convection. When under a vessel of water A A (fig. 169), heat is generated by a lamp B, the portion near the bottom is dilated, and rendered specifically lighter; which ascends, and the colder and denser particles sink down to their place, and in their turn ascend. A continued current is thus created, the heated particles rising in the centre, as at C C, and the colder ones descending at the sides, as represented by the arrows D D: by thus constantly changing the particles, the heat is spread over the mass of water, and the whole is sooner at the boiling-point than the same could by conduction be made to pass into a solid. A popular experiment is shown to prove that water is a bad conductor of heat; this consists in having a hollow tube, at the bottom of which is placed a piece of ice, kept in its position by a small weight, and the rest filled up with water; the tube being held slantingly, a spirit-lamp is applied near the top, when the water in that part is made to boil while the ice remains unmelted.

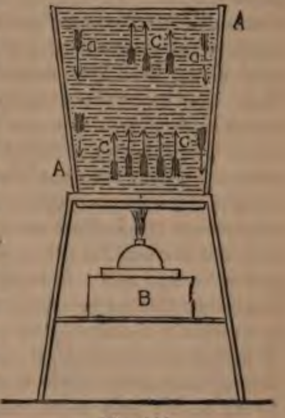


Fig. 169.

If a piece of paper be wrapped around a piece of wood, and passed slowly through a flame, it will be speedily consumed in comparison to a similar roll of paper around a bar of iron; this arises from the wood less greedily absorbing the heat than the iron, consequently there is more heat left to consume the paper around the wood than that around the metal.

Air when heated ascends or moves away; causing the colder air to rush in, producing the delightful variations of warm and cooling breezes; and, in fact, the circulatory movement of the whole atmosphere. If a lump of ice be introduced into an apartment, the air in immediate contact with it becomes denser and sinks, other air rushes to supply its place, and ultimately the particles of heat in the continually renewed air melt the ice. If a tube be nearly filled with water, and a lamp applied, as shown in fig. 170, the water at the upper part would boil, whilst that at the bottom would remain cold as at first. It may be inferred, then, that were the atmosphere heated at its surface, as the water in the tube, there would be no equality of temperature, by which both the Torrid and the Arctic Regions are rendered habitable; but as the heat proceeds from the bottom of the aërial ocean, it is warmed as the water described in the vessel, by upward currents, as exemplified in fig. 169. Now it is plain the waters of the globe cannot be heated by convection, but only by conduction, which is so slowly accomplished that deep waters always remain cool. When frost descends, it causes the surface to be cooled and dense, then sinks to the bottom,—and forces up warmer water to its place; this in its turn sinks; and this system of carrying or convection keeps up a circulation until the whole mass from top to bottom has increased in density and occupies less space. Were the water to reach 32 degrees of cold, it would begin to freeze at the bottom; but, by a wise provision of Providence, when the surface-water is about $39\frac{1}{2}$ degrees of temperature, the usual operations of nature seem to change; it begins to expand and have less density, and ice forms a crust over the surface, protecting the fluid underneath from the frigidity of the atmosphere, actually warming the lower water, and preserving the lives of the living creatures underneath. From the whole mass of water throughout having to become dense before the process of ice formation commences, the deep seas of cold climates are not frozen, or the lakes that rest in deep basins. The cooling of the water by the givin

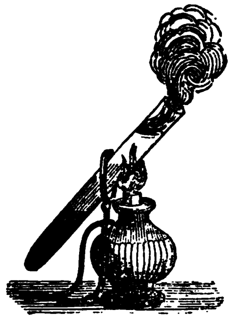


Fig. 170.

off of the heat that it contains, serves to add the lost warmth to the surrounding atmosphere, which accounts for inland parts of countries being colder than those parts near the sea, even when in a warmer latitude. In summer the humid breeze of the ocean preserves on its shores a cooler atmosphere than is enjoyed by inland parts. Thus the coasts of Scotland and Ireland have neither the heat of summer nor the cold of winter felt in the British metropolis. This is because their breezes in winter come from over the ocean, which, not being frozen, is warmer than the land; and in summer, the sea not being so heated as the land, the winds are cooler. Frost in England penetrates but a few inches below the surface; in all parts of the world, at a small depth below the surface, the temperature is nearly equal: and it is in this way the life of the vegetable kingdom is preserved.

Absorption of Heat.

All substances absorb the heat to which they are exposed in a more or less degree. When bodies are exposed to the sun, in a given time one may absorb a considerable quantity of heat, and another very little. This is demonstrated by an instrument called a differential thermometer (fig. 171), already alluded to, and used to observe the laws of radiant heat. It consists of two tubes placed perpendicularly, having bulbs at the top with graduated scales fixed to them; the tubes are continued horizontally, so that they become as it were but one bent tube with bulbs at the extremities. Into the tube is put some coloured sulphuric acid: the bulbs being full of air, when the temperature is equal in both bulbs the acid is of course at the same height on both sides; but when one bulb is exposed to heat, the air in that bulb expands, and pressing upon the liquid, drives it up the other side of the tube, and stands highest in the coolest. The difference of temperature is then observed on the graduated scale.

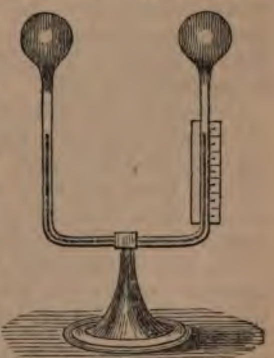


Fig. 171.

This thermometer will show that the power of absorption depends mainly on the nature of the surface; for if both bulbs be exposed to the same degree of heat, and one have a coating of lamp-black, while the other is in its natural condition, a considerable difference in temperature will be observed; and by covering one of the bulbs with any particular substance or colour, its power of absorbing heat may be ascertained. A bright metallic substance spread over a bulb possesses scarce any absorbent power, while black paper or cloth exerts it to a great degree.

A black coat is the warmest covering in summer and the coldest in winter. In summer the body is frequently cooler than the external atmosphere; and a black coat, absorbing the heat, raises the temperature of the body; in winter the body is warmer than the atmosphere, and then the black cloth radiates the heat from the body.

The shaggy coat of the Polar bear is white, so as not to radiate the heat of the body of the animal, and to enable it to sustain the rigours of an arctic winter.

When sailors are ordered on the various arctic expeditions, they are provided with clothing of a kind of sky-blue or French-grey colour, both as one of the best to preserve the heat of the body from being radiated, and a tint of colour sufficient to render them distinguishable on the white ground, and prevent them being mistaken for bears on two legs, which their muffled uncouth appearance might lead some of the nautical hunters to imagine them to be.

Colours possess different properties of absorbing heat; and Dr. Franklin, by experiment, found those which absorbed most light absorbed most heat. He laid pieces of different coloured cloth on snow, and watched them for a time while the sun was shining upon them, noting the different depths to which they sank by the melting of the snow underneath.

The rays of heat that pass into a body are seldom entirely absorbed; unless the body be thick, a great part of the heat will pass through and continue an onward course.

Radiation of Heat.

Heat transmitted through space, and coming from bodies in rays, is termed *radiant* heat.

If a red-hot cannon-ball A (fig. 172) be suspended by the

wire E, heat will be found to radiate from it in all directions' the intensity of the rays diminishing in regular proportion to the distance; thus at three feet, as at *b*, there is nine times less heat than at one foot *a*; sixteen times less at four feet *c*, and twenty-five times less at five feet *d*. These rays are instantaneously diffused and given out in straight lines like those of light. When the rays are stopped and swallowed up or absorbed, then the absorbing body is increased in temperature. Heat passes best through the worst conductors, air and gases; while metals arrest its progress, and if polished, reflect it. Heat, although it accompanies the sunbeam, can be separated from light. Like light, it may be brought to a focus, as in a burning glass.

Fig. 172.

Inequality of temperature exists among objects exposed to the same degree of heat, from the various properties they possess of absorbing and parting with heat, which depends on their conducting powers and the state of their surfaces; and it is remarkable that the absorbing and radiating powers are very frequently proportional. If the radiating power of lamp-black be 100, writing-paper is 98, sealing-wax 95, crown-glass 90, ice 87, plumbago and isinglass 75, tarnished lead 45, mercury 20, clean lead 19, polished iron 15, tin-plate, gold, silver, copper, and tin polished 12. Thus a vessel covered with lamp-black will cool down hot water in half the time to what it would if it had a polished surface; but water in a polished vessel may be quickened in its cooling by enveloping it in thin cotton or woollen cloth. This may arise from exposing to the atmosphere a larger surface, as a roughened one both receives and gives out heat more rapidly than a smooth one. There is this difference between the heat from the sun and that produced by artificial means, as from a fire; the first darts

through air, glass, water, and other bodies, whereas the latter is arrested in its progress. We have stated that the rays of the sun pass through the air without leaving much of the property of heat; they fall on the surface of the earth, and by convection the atmosphere is heated. But all the rays of heat do not pass into the earth, for some are reflected; and according to the angle of incidence is the angle of reflexion.

The apparatus for concentrating and showing the effects of the radiation of heat consists of two metal mirrors, highly polished. These have the form called paraboloid; any number of rays coming from the focus are reflected into parallel directions, which coming to such another mirror, are all reflected so as to meet in its focus. *n p* (fig. 173) are the two concave mirrors placed exactly opposite each other, so that all the rays of light or heat issuing from the focus of one may be collected in the focus of the other. If a red-hot ball be placed at *b* in the focus of *p*, the rays passing from the ball to *n* will be reflected in parallel lines to *p*, and reflected from it to meet in its focus *a*. If gunpowder, phosphorus, charcoal, or paper be placed at the focus *a*, they will be fired or burnt; and if a thermometer be within the influence of the focus *a*, it will be more affected than if near to the heated ball. If a piece of ice be substituted for the hot iron, the mercury in the thermometer will fall. This made many persons think that cold had a positive existence, which was an error, as cold is a mere sensation from the lessening of heat. In this case the hot ball radiates heat in all directions; and the rays that act on the thermometer are only those that fall on the surface of the reflector, from the part of the ball opposite to it. If the thermometer be held out of the focal point, or in any part intercepting the heat-rays, a change of temperature will *hardly* be perceptible. The thermometer being of the heat of

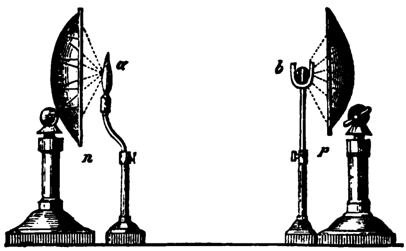


Fig. 173.

the room in which it is placed when opposed to the piece of ice, is then the hot body, and radiates its heat to the ice; consequently its temperature falls in proportion as it may be above that of the ice. Hence it is not rays of cold, as many suppose, that affect the thermometer, but the radiation of heat from it to the ice.

When the face of one of these mirrors is turned directly opposite to the sun, the focus has the power of burning with intensity; but if turned to the zenith of a clear blue sky, the thermometer presented to its focus sinks considerably: this arises from the mirror intercepting the heat which would reach it from the earth, and the absence of clouds to reflect back the heat: when clouds intervene, the thermometer rises at once. This teaches us that every thing on the earth is radiating heat, and that the clouds in the heavens perform the same office. When the sun passes from our view to distribute its favours to other lands, the radiation of heat still goes on; the earth's surface, which in the day was warmer than the superincumbent atmosphere, parts with much of its heat; and the moisture held in the air is condensed, forming those globular gems that bedeck every leaflet and blade of grass, which we name *dew*.

When the sky is cloudy there is little or no dew, as the heat radiated from the earth is sent back from the clouds. The moisture of the atmosphere being lessened, and so much heat liberated by the formation of dew, the air is consequently warmer. Gardeners, to prevent dew falling on some plants, cover them at a short distance from the earth with calico or other thin material, and thus arrest the free radiation of heat from the surface. The pearly drops that form on vegetation are but scarce on rocks and barren earth, arising from these bodies being bad radiators of heat. The cooling of the atmosphere, then, is the reason of the formation of dew, and the temperature at which it is deposited is termed the dew-point; the difference between the dew-point and the temperature of the atmosphere, shows the dryness of the air; and this is found by means of an instrument called a hygrometer.

The heat from the rays of the sun is increased the nearer the body receiving it is placed at right angles. A knowledge of this has led to an improvement in the growing of wall-fruit, a slanting roof instead of a perpendicular wall being found to

[illegible] and the rougher the [illegible]

[illegible]

[illegible] a body is not [illegible] another substance [illegible] the thermometer [illegible] heat may in [illegible] of heat. If two [illegible] be mixed, the [illegible] But if the liquids [illegible] mercury, if [illegible] with a pint of [illegible] the heat [illegible] the water at [illegible] mercury has [illegible] of these different [illegible] different quantities [illegible] in order to raise them [illegible]

[illegible] requires as much [illegible] that degree of [illegible] of water.

[illegible] In fact, the water [illegible] as the mercury. [illegible] water will liquefy [illegible] equal weights of [illegible] water and [illegible] the water will heat the mercury [illegible] weights. [illegible] be reversed, the water cold and the mercury [illegible] will lose [illegible] of heat in [illegible] Water, under the ordinary pressure of the atmosphere, boils when it has a temperature of 212°, and no increase of heat will raise it above that point. These circumstances of susceptibility to heat in equal weights of different bodies are termed their *capacities for heat*.

Latent Heat.

Heat is the great cause of the separation of the particles of all bodies. It transforms a solid into a liquid, a liquid into a gas by its repulsive property. A great portion of the heat so

engaged is incapable of being communicated to other substances, and remains *latent*, or hid, so long as the gaseous or fluid condition is maintained. To transform ice at 32° into water at the same sensible temperature, demands a considerable addition of heat (140°); all of which becomes latent in the water. To change water at 212° into steam at the same temperature, 1000 more degrees of heat are needed, which become latent in the steam. This cause checks a too rapid liquefaction or evaporation, and causes both to produce cold, by depriving surrounding substances of their caloric.

The heat thus lost, when a solid is converted into a liquid or either into a gas, is called *hidden* or *latent heat*; and its discovery is owing to the researches of Dr. Black, who found that whatever time was necessary to heat the ice one degree, exactly one hundred and forty times as much would be required for melting it, thus that 140° is the latent heat of water; and Lavoisier, a celebrated French chemist, invented a heat-measure or calorimeter, which consisted of a vessel lined with ice; and the quantity of heat given out by any body placed in it is indicated by the quantity of water collected from the melted ice.

The calorimeter is made of tin or iron plates A A (fig. 174), and inside is a smaller one B B, in which is a wire vessel C, to hold the substance that is to be tested. Between the first and second vessels, as also between the second and the wire cage, the space is filled up with pounded ice. The ice between A and B prevents the warmth of the atmosphere acting on the enclosed substance; thus the ice around the wire vessel is affected only by the heat from the substance examined, which melts the ice until its temperature reaches 32°. The ice thawed by the substance runs off as water at the cock D, and is afterwards weighed. As melting ice is always at 32°, all the heat applied goes to thawing the ice; and therefore as to the quan

Fig. 174.

melted so is the amount of heat expended. A pound of water 135° above freezing-point will melt 1 lb. of ice.

The latent heat of water is 140°; of mercury, 142°; melted wax, 170°; tin, 442°; zinc, 492°. The latent heat of vapours is usually high. That of steam is 1000°; of vinegar vapour, 900°; alcohol, 442°; ether, 300°; oil of turpentine, 177°.

It is this latent heat dwelling in bodies that prevents the freezing of the earth or ocean, or the instantaneous conversion of snow into water, and allows the changes to be gradual and foreseen. Metals slowly melt or become hard from the same cause.

Latent heat is beautifully illustrated in the slaking of hot lime; the water poured upon it becomes solidly combined with the lime, while the latent heat is liberated from the chemical action that takes place. The heat given out by steam-pipes is the latent heat given up by the steam which is condensing into water.

The elasticity of vapours depends much on the quantity of latent heat they contain. On undergoing forcible compression, they give out much of this heat, for they require less when they occupy less space. On again expanding, the gas or vapour acquires heat, and produces cold by taking it from bodies around.

This is illustrated by an instrument named the atmospheric tinder-box, by means of which tinder and other easily inflammable substances are ignited, from the rapid condensation of air. It is made of glass or brass, about 10 inches long, hollow, and very small in the diameter. A piston *a a c c* (fig. 175), attached to a rod *b*, works in the tube *e* and fits very exactly; in a hollow *d* on the lower part of the piston is fixed the tinder, or amadou, and on the operator driving it suddenly down to the bottom, ignition takes place.

Fig. 175.

When we desire to warm anything with our breath, we open the mouth and send a stream of warm air from the lungs slowly and gently; but if we want to cool a hot substance, we contract the muscles of the chest, narrow the mouth to a small aperture, and blow quickly and strongly. If air be compressed into a cylinder vessel with the weight of

three atmospheres, and then allowed to escape through a very small hole, the heat rendered latent by the air in its expansion as it passes out will cause such cold as to freeze water.

Heat causes change of state.

In considering heat as a cause of expansion, we have already mentioned that almost every body in nature is susceptible of three states of existence, solid, liquid, and aëriform; and that these conditions depend on the quantity of caloric or heat they contain. Thus water may be in the state of ice, water, or steam; mercury may be as a solid bar, liquid, and as gas. At the ordinary heat of the atmosphere some objects are solid, as metals and stones; some liquid, as water and oils; others are air, as nitrogen and hydrogen. This is dependent on their relation or affinity to heat.

Oxygen possesses an immense affinity for heat, and although it exists as a gas, may be combined to a solid, as in the case of the rust of iron. But beside this combination, Dr. Faraday, by compression and cold, has both liquefied and solidified many gases. The application of heat to solids has the effect of first expanding their bulk; some become softened, and others at once pass from the solid to the liquid, and then, on continuing the heat, to the gaseous form; while some pass from the solid to the gaseous without becoming liquid. To a certain point some solids will receive heat and preserve their conditions, but beyond that point will change. It is a singular fact, that what is called the melting- or freezing-point is always exactly the same in the same substances; thus ice melts, or water freezes, at 32° on Fahrenheit's scale. The freezing-point of mercury is 40° below zero.

Diathermancy.

The radiant heat which falls on the surface of a body is in part absorbed, in part reflected, according to its nature, and a part may be transmitted. Some transparent and translucent bodies, which allow a ray of light to pass through them, permit a ray of heat to pass also. For this property the term *diathermancy* has been invented by Melloni, who has abundantly investigated the subject. Many bodies are transparent to light, but only one solid—rock-salt—allows most of the ray of heat to pass it. Rock-salt transmits 92·3 per cent. of the

heat which impinges upon it; it is the most diathermanous body known. Native crystals of sulphur transmit 74 per cent.; fluor spar, 72; quartz, glass, and Iceland spar, 39; tourmaline, 18; citric acid, 11; alum, 9; white sugar-candy, 8. Of liquids—sulphuret of carbon allows 63 to pass; olive oil, 30; alcohol, 15; and water, 11. There is no direct relation between diathermancy and transparency. Crystallized sulphate of copper transmits blue light, but entirely arrests heat. Black mica and smoked glass are opake to light, but transmit a considerable amount of heat.

One curious fact noted by Melloni, is that heat from different sources had different powers of passing through such media. Rock-salt alone transmits alike all kinds of heat. With other media, the heat of a naked flame has the greatest power of passing; that from ignited platinum has less; that from copper heated to 750°, less still; and that from copper heated to 212°, least of all, being entirely arrested by plate-glass, citric acid, alum, &c. Thus there is probably some variety among different rays of heat, as of light.

The thermic rays may be *refracted*, like those of light, and brought to a focus by a lens or burning-glass. A prism of rock-salt being caused to refract a ray of heat, there is formed a sort of thermic spectrum, over which the rays of heat are distributed. Most of these rays are less refrangible even than the red ray of light, and are found situated in the dark space beyond the red ray of the solar spectrum. Heat is found to be more refrangible in proportion to its greater intensity.

Homogenesis of Forces.—"There is no question occupying more attention among the highest order of intellects than that of the identity of the several invisible forces of Nature. The relations of magnetism, electricity, chemical affinity, heat and light, are certainly very close and very complicated. Each one of these forces is capable of producing either or all of the others. They may also all generate mechanical power, and mechanical power, on the other hand, may generate all of these forces. Perhaps as good an illustration of this as any is to be found in the electric light. First, the mechanical power of a *steam-engine* turns a wheel which carries a number of permanent *magnets* at its periphery; these magnets, as they are carried past the ends of soft iron cores which have insulated wires wound around them in helical form, cause waves of *elec-*

tricity to flash through the helical wires; the electricity, darting along from drop to drop of an exceedingly slender stream of flowing mercury, produces an intense *light*; it also generates *heat*, by which the mercury is evaporated. But whence comes the mechanical power of the steam-engine? That results from the expansion of steam caused by heat, and the heat is produced by the combustion of fuel, which is its chemical combination with oxygen; in other words, *chemical affinity*. If we replace the steam-engine by a water-wheel, we have the several forces produced by *gravitation*. It is to be remarked, however, that gravitation cannot be generated, in its turn, by any of the other natural forces, or by mechanical power. From these several facts, and others of the same kind, the grand and simple idea has been suggested that all the forces in Nature are the same thing; merely *matter in motion*. This suggestion implies that all the countless phenomena of chemical combination,—all the appearances produced by light, its endless variety of colour and shade, its refraction, reflexion, and polarization, with the miraculous revelations which these have given us through the telescope and the microscope,—the tremendous power of heat, with its contractions, expansions, freezings, and evaporations,—all the swift and subtle operations of electricity in the galvanic battery, the lightning-rod and the telegraph; and, finally, the growth and decay of plants and animals, the action of the muscles, the stomach, the lungs, the nerves,—in short, all the phenomena of the universe,—are produced merely by changes in either the velocity or the direction of the motions of matter. Such is the doctrine of the homogenesis of forces. A sublime and comprehensive theory, whether true or false! A few scientific men have committed themselves to it fully; but most able philosophers regard it yet as unproven. As the relations of the natural forces to each other caused the conception of the theory, so the promulgation of the theory has led to a very close study of these relations; and the field is as rich in curious and wonderful facts as any that has ever been explored by the student of Nature."

Cold, or the Absence of Heat.

Cold has no existence of its own, but is merely a negative quality. It represents the absence of heat to a greater or less

extent. The less the heat, the greater is said to be the cold. The sensation of cold is felt when heat is abstracted from the body.

Heat may be lost, and cold produced, in several ways:—First, by conduction; contact with a good conductor causes a heated body to part rapidly with its heat until an equilibrium is produced. The hand when placed on a metal surface feels cold. Secondly, heat may be lost by radiation. The heated substance radiates heat away into surrounding space. The human frame, if deprived of clothing, quickly becomes cold by conduction and radiation. The rapidity of cooling by radiation depends chiefly on the nature of the surface, as already stated. Bodies naturally become cold when the usual source of heat is cut off. The withdrawal of the sun's heat causes a degree of winter's cold varying from the freezing of water in the temperate zone to the freezing of mercury in the arctic regions.

A change of condition in matter causes cold: when a gas becomes a liquid, or a liquid a solid, heat is abstracted to supply the amount needed to become latent.

When snow and salt are mixed they mutually liquefy each other, and a greater degree of cold is felt than in either of the bodies in a separate condition, which arises from the sensible heat both of the salt and snow becoming latent during liquefaction; the glass or other vessel holding the mixture also loses part of its heat, and the more rapid the liquefaction the more intense the cold. Not only does this take place in salt and snow, but also in other crystalline substances that are capable of mutually liquefying each other: this has been turned to account for the production, in hot weather and in hot climes, of the luxury of iced drinks. The mode adopted by Mr. Walker consists in having broad tin cylinders with thick sides, in which are enclosed two cylinders, one within the other, with thin sides of the same height as the outer one, and fastened together at the bottom. In the innermost cylinder, and in the space between the first and second, is placed a freezing mixture, consisting of 5 parts of hydrochlorate of ammonia, 5 parts of nitrate of potass, and 10 parts of water at a temperature of 50°; the substance to be frozen is then put into the space between the second and third cylinder, and the cold produced by the mixture lowering the temperature to 10°,

the water or other substance last put in quickly becomes a solid piece of ice.

By a freezing mixture of solid carbonic acid with sulphuric ether, alcohol has been made to have the consistency of oil, or even of melted butter. In people rising from a bath, the evaporation of the water from their bodies carries off with it a portion of the heat, and thus they feel cold. On this principle are wet cloths wrapped round bottles of wine; a common mode of cooling wine on board ship. The bottle is at the same time suspended from some portion of the rigging to hasten the evaporation.

Water may be frozen by evaporation, as is exemplified in the following experiment by Leslie. He placed a thin metal cup *a* (fig. 176) on a tripod stand *b b*, and put it into water; and a dish about two inches distant underneath, *c*, he filled with concentrated sulphuric acid to within half an inch. This apparatus being on the plate of an air-pump, and covered by a glass *d d*, on the air being exhausted the vapour of the water rises to fill the vacuum; but as sulphuric acid has a powerful affinity for water,

Fig. 176.

it absorbs the vapour as fast as it is formed, thus producing a very quick evaporation; and the latent heat being carried off by the vapour of the water, the remainder of the water is frozen.

Snow.—If the temperature of a cloud should fall at any time to 32° Fahrenheit or lower, instead of rain the result is snow. Much that is beautiful and beneficent is seen in this divided form of frozen water. In our own temperate clime we do not comprehend, except by reflexion, the true value of snow in the economy of nature. But if we would desire to recognize the full benefits of snow, we must direct our attention to northern countries—to Sweden, to Russia, and Canada. There the advent of snow is looked forward to as a blessing; and when it comes, the period of its duration admits of being predicted with tolerable accuracy. No sooner is the ground covered with sufficient snow, than wheeled carriages, which but yesterday were sticking up to the axle-tree in mud and we are put aside, and sledges supplied in their stead. Market-

places, which before the snow had fallen were naked and unworthy, now teem with good things brought from hundreds of miles away. Snow has all at once laid down a far-stretching railroad, over which sledges glide almost with the ease and velocity of a railway train.

In certain conditions of temperature, snow falls as a pulverulent body, in other conditions as a flaky amorphous mass; but if very dry snow be microscopically examined before it has been broken up, indications of crystalline structure will be recognizable. Sometimes these crystalline snow-flakes attain such large dimensions, that they are quite evident to the naked eye. The crystalline forms thus developed are numerous, but they are all referable to one crystalline system, the *rhombohedric* or *rhombohedral*; the characteristic of which is that crystals belonging to it have three axes crossing each other at the angle of sixty, and one axis at right angles to these. Scoresby, who has minutely examined these snow-flakes, describes four principal forms of snow-crystals:—1st, crystals having the form of thin plates, which are the most abundant; 2nd, surfaces or spherical nuclei, with ramifying branches in different planes; 3rd, fine points, or six-sided prisms; 4th, six-sided pyramids. The latter form is the least frequent of all. See fig. 3, p. 8.

Inasmuch as the upper regions of the atmosphere are intensely cold, there is an elevation for every latitude at which atmospheric moisture is changed into snow. This elevation corresponds with what is termed the *snow-line*. At the equator the snow-line is elevated from 11,000 to 12,000 feet above the sea-level. As we proceed towards the north, the elevation of the snow-line will evidently be lower. Snow does not fall on level ground in Europe further south than Central Italy; but in Asia and America the region extends nearer to the equator. Through Florence passes the isothermal line of 59° Fahrenheit, and it may be regarded as the southern limit of the region in which snow falls on level places. Snow does not usually fall at the time of maximum cold; some meteorologists say it never does; but this is an error.

After snow has fallen the weather generally increases in severity. We are usually in the habit of assuming that the total quantity of snow which falls increases as we reach either pole—an assumption, however, which is only correct within

certain limits. Thus, taking the northern hemisphere, for instance, the fall of snow increases from the isothermal of 59° Fahrenheit to the isothermal of 41° Fahrenheit, which latter cuts the town of Drontheim in Norway. Passing still further north, the quantity of snow goes on diminishing, evidently because in the polar regions the temperature of the air is too cold to retain much moisture, and atmospheric moisture must necessarily be the antecedent to either rain or snow.

The atmospheric condition during the fall of snow may vary from the limits of almost complete tranquillity, to the other extreme of most violent perturbation. In Germany, and other countries having a corresponding latitude, the fall of snow is usually tranquil, except during the months of February and March. In high latitudes snow usually occurs during violent tempest-gusts, almost equal sometimes to the West Indian hurricane or the Chinese typhoon. In Norway these storms are very frequent, also in Kamtschatka; in which latter region they are called *purga*. They are veritable thunder-storms, as is completely proved by the intense electrical condition of the atmosphere. On mountainous elevations snow-storms are commonly prevalent, irrespective of latitude.

Ice.—As heat causes the expansion, cold causes the contraction and solidification of matter. The temperatures at which substances become solid vary much. They are called freezing-points from the term applied to the congelation of water. Ice is a remarkable exception to the rule just stated, that a solid occupies less space than the liquid which congeals into it. Ice occupies more space, and is specifically lighter than water. Thus water rises on freezing; a layer of ice forms on the surface of a pond or river, and prevents the water beneath it from becoming one solid mass. By this the fish and other inhabitants of water are protected from utter destruction. Sea-water contains many salts, so that it does not freeze at all until 28°. Then lumps of pure ice separate, and the salts are left dissolved in the remaining water. The freezing of the sea takes place on an extensive scale during the extreme winter cold of the Arctic regions. A large body of water freezing in a confined space forms a mass of ice, which, by its own expansion, is split up into pieces. In this manner are formed the fantastic pinnacles seen in some of the great ice-fields or glaciers

of the Alps, as in the lower part of the Glacier des Bossons at Chamouni.

Fig. 177.

CHAPTER IX.

OPTICS—LIGHT.

That branch of science which treats of the nature and laws of vision is called *optics*; and as it is by the medium of *light* that objects become visible, the two subjects naturally become blended, and form most interesting themes of scientific inquiry.

Nature of Light.

Light is something which is given off in straight lines, in a radiating manner, with extreme velocity, from bodies which are called luminous. It is reflected from the surface of some bodies, absorbed or annihilated by others, allowed to pass through by a third group, undergoing frequently some change of direction during this transmission. It is imponderable,

and we have every reason to believe it unsubstantial. Unlike heat, it enters into no combination with matter, but ceases immediately that its source is cut off. In this character of depending entirely upon an active source, and having no permanent existence of its own, it resembles sound, to which we shall see hereafter that it is probably analogous in many particulars. Light affects the sense of vision, and does not impress the sense of feeling; in this again it differs widely from heat.

Light cannot be more closely defined than this. As to its intimate nature we know little, but we can guess more. There are two theories which have been propounded on this point. The theory of *emission* supposes that light consists of some inconceivably minute particles projected with immense velocity from luminous bodies. This is also called the Newtonian theory, but it was adopted by Newton simply as a convenient hypothesis. The other theory is called the *undulation theory*. It substitutes *undulations* for particles. These undulations or vibrations cannot take place in any material body, or in any medium with which we are acquainted, as light traverses a vacuum and passes unopposed through the regions of space, where there is no atmosphere. As there must nevertheless be some medium, it was necessary to assume the existence of an imponderable medium of extreme tenuity pervading all space. This hypothetical fluid is called æther. If we assent to the undulation theory, we have no choice but to acquiesce in the supposition of this fluid, which, *when vibrating, is light, when at rest is darkness.*

The undulation theory is the only one capable of explaining some curious phenomena of light lately discovered (see paragraphs on *interference* and *polarization*). It accounts in a beautiful manner for the extraordinary fact that one ray of light is capable of neutralizing another, and producing darkness. The analogous phenomenon in acoustics, that two sounds may produce silence, is at once suggestive of the idea of a similarity in causation between sound and light.

The undulations of light are supposed to be infinitely more minute than those of sound, and travel with a speed almost incredible. There are also many different kinds of undulations, as there are varieties of rays of light. For the ray of white light that comes to us from the sun can be proved

by a simple experiment to be of a compound nature, and to consist of seven distinct coloured rays amalgamated into one white one. Of this important fact we shall speak again directly.

Sources of Light.

To this earth the sun is the great source of light as well as of heat. The sun's ray contains besides heat and light, a third principle, or property, of chemical excitation, called *actinism*, which some consider to be a part of light, and is certainly intimately associated with it. When the sun leaves us at night, light does not cease to come to us from the heavens, though we are in a state of comparative darkness. The light of the moon is that of the sun reflected from the surface of our earth's satellite. When the moon does not appear, or when the earth lies between it and the sun, sunlight is more faintly reflected from the planets of our system, which have also but a 'borrowed lustre.' The fixed stars shine upon us by their own light, though from an enormous distance. Some light is derived more directly from the sun by refraction through the atmosphere at night-time; so that even in the darkest night there is no *absolute darkness*.

Light is further evolved by all bodies that have reached a certain degree of heat. It is thought that the temperature at which this incandescence or luminosity occurs, is about the same for all matter, being nearly 1000° Fahrenheit. Infusible stones, as lime, and metals, as platinum, evolve light when heated to this point. As all combustible bodies rise to about this temperature in the act of burning, it follows that light is given off during combustion. In the combustion of solids, liquids, and gases, as wax, tallow, oil, coal-gas, lies our great source of artificial light. By such means we may obtain at night-time an illumination almost rivalling day in brilliancy.

The phenomena of phosphorescence, as observed in some mineral bodies, in many animals (as the Medusæ), and plants (as the Dictamnus), depends probably on electricity. Electricity is another cause of light, which is seen in a vivid form, accompanied by heat, in the electric spark. By interposing a non-conducting combustible body, such as charcoal, between the poles of a powerful battery, the electric light is obtained.

The *degree of illumination* from any source depends upon

the intensity of the light excited in the luminous body,—the distance of the illuminating body,—the amount of *absorption* which the rays undergo in traversing the intervening media,—and the angle at which the rays fall upon the surface of the body illuminated.

The sun produces the most intense light of any body with which we are acquainted. Dr. Wollaston calculated that it would require 20,000 millions of the brightest stars, such as Sirius, to equal the light of the sun, or that that orb must be 140,000 times further from us than he is at present, to be reduced to the illuminating power of Sirius; the same authority has determined that moonlight is 801,072 times weaker than sunlight.

The illuminating power of the planets, the earth being 1, is as follows:—

Earth	1·00
Venus	2·00
Mercury . .	6·00
Mars	0·44
Jupiter	0·04
Saturn	0·01
Uranus	0·0025

It will be understood that these illuminating powers of the planets depend upon the distance these orbs are from the sun and from our own earth.

In artificial light, the illuminating power is in exact ratio to the quantity of solid matter which changes form. Pure hydrogen gas has a very small illuminating power; but if, by passing it through any fluid containing carbon, as naphtha or spirits of turpentine, it is made to take up a portion of this element, it burns with great brilliancy.

Matter as related to Light.

Bodies are said to be luminous, opake, and transparent. Luminous bodies are those which, within themselves, possess the property of exciting the sensation of light or vision, as the sun, the stars, electricity, the fire, the candle, hot iron, phosphorus, the glow-worm, and others. Some opake or non-luminous bodies have the power of shining from a borrowed light, as a polished metal, the light received from a luminous body by it being reflected to others; but without this borrowed light it would be dark. Opake bodies prevent light

from passing through them. Transparent bodies are those that have the property of allowing light to pass through them, as air, glass, water, &c. They are sometimes called mediums by which light is transmitted. Strictly speaking, substances are only transparent through which light passes freely, and objects can be seen distinctly, as glass, horn, &c. The term translucent is applied to those that permit the light to pass freely through them, but through which bodies cannot be discerned, as ground glass, paper, porcelain, &c.

The salts composed of metals or earths with acids, that constitute crystals, are generally transparent; but when crushed to powder, they are opake. Metals which in thick masses are opake, when in solution may be beautifully translucent; or when some are reduced to a thin leaf, they allow light to traverse them. Transparent bodies do not transmit all the light that enters them. Air arrests a considerable portion of light as it passes through it; and water does not allow it to penetrate a depth beyond seven feet, without absorbing one-half of its quantity. Practised divers know that in the clearest water they soon find darkness as they descend, and that the bottom of the ocean is a world without light.

Velocity of Light.

It was believed that the velocity of light was instantaneous, until astronomers discovered, in the eclipse of one of Jupiter's satellites, that the motion of light was progressive. They watched the satellite entering his shadow when that planet was nearest the earth, and found that the light reflected by it look about 33½ minutes in reaching us, and when furthest from it about 50 minutes; hence proving that the rays of tight were 16½ minutes in travelling the diameter of the earth's orbit, or 8¼ minutes in passing from the sun to us, a distance of 95,000,000 miles. Multiply the 8¼ minutes by 60; to reduce them to seconds, and divide the distance by the seconds, and it will be found light has a velocity of about 192,000 miles in a second.

Peschel observes: "A cannon-ball moving with a uniform velocity of 2450 feet in a second, would be 6½ years, and sound would be 14 years in coming to us from the sun; a cannon-ball moving with the same velocity as we have already supposed, would be 16 hours in travelling round the circum-

ference of our earth, a space which light traverses in one-eighth of a second: the velocity of light must therefore be half a million times that of a cannon-ball, and more than a million times that of sound. At the rate of 4 miles in 3½ minutes, being the speed at which Brunel, in 1841, travelled on the Great Western Railway, it would require more than 137 years to go from our earth to the sun."

When the moon is full, the light it reflects amounts only to about a hundred thousandth part of that of the sun; its distance is ten times the earth's circumference, consequently scarcely a second and a half is occupied by light in its journey from the moon to the earth. From the planet Neptune, at a tremendous distance, light is five hours in reaching us; it is years from the nearest fixed star, and centuries from the nearest nebulæ. Sir William Herschel stated, when writing upon the power of telescopes to penetrate space, that the light seen by him at that time by means of his powerful telescope cannot have been less than one million and nine hundred thousand years in its progress.

Of Shadows.

The rays of light under ordinary circumstances are emitted in direct lines, as proved by their not passing through a bent tube; also, as the substance on which they fall and the shadow form right lines with the ray. When light meets with an opake body through which it cannot pass, it is stopped, and darkness produced on the opposite side. This is a shadow. During night we are living in the shadow of the earth; the light from other bodies, however, prevents total blackness or darkness. Thus if a globe be held before a gas-light or candle, the shadow on the opposite side to the light will only be faint; but if the gas-light be lowered, or a smaller candle replace the other, the shadow will be deepened, though not entirely dark, from the reflexion of the wall or other objects. As in the case of the sun *a a* (fig. 178) to the earth,

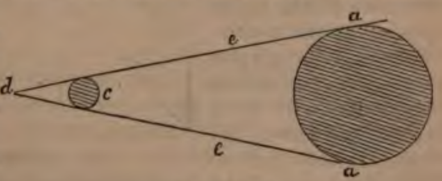


Fig. 178.

a large luminous body illuminating a small opake one *c*, the shadow *e e* produced gradually tapers off to a small point *d*. But when the luminous body *a* (fig. 179) is smaller than the opake one *b*, the shadow *c d* will gradually increase in size. This may be familiarly illustrated in a room with a candle: if the candle be at some distance from a person who is between it and the wall, the shadow will be about the same size as the person's body; but as the candle is brought nearer to him, the shadow will be enlarged. If two candles be placed in different directions beyond an opake body, there then will appear two shadows; if three, three shadows; and so on.

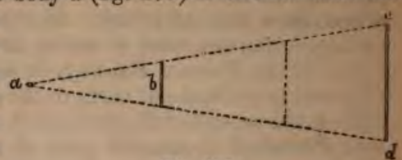


Fig. 179.

There is this singular property in the rays of light, that they pass directly onward in a straight line, crossing each other in every direction, but never interfering the one with the other. Thus, as shown in the illustration (fig. 180), the light from three candles cross, the one proceeding in a line, and the others at angles; and each reflects different faint shadows of the object placed in the centre. The small triangle just beyond the little arrow or figure will be a strong shadow, because in that part no light from any of the candles reaches there, being obstructed by the figure and enclosed by the lines indicating the shadows from the three candles.

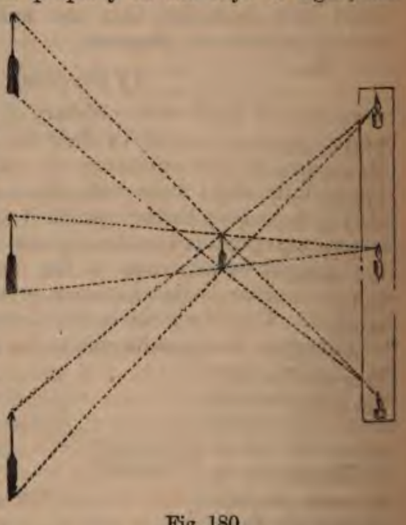


Fig. 180.

If a hole be made through a partition, and six or more candles be placed on one side of it, the rays from each will pass through the hole and cross each other, reflecting the light of each on a part of that apartment where the candles are not.

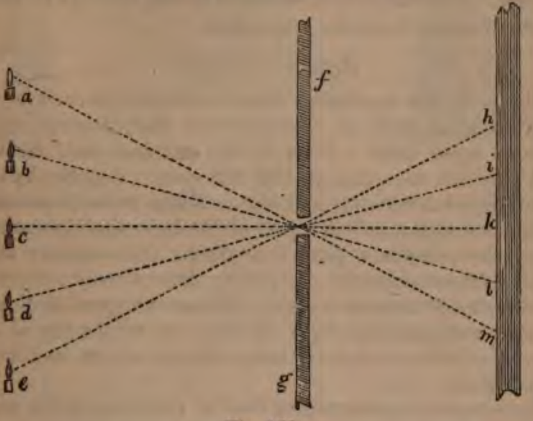


Fig. 181.

This is illustrated in fig. 181, where *a, b, c, d,* and *e* are candles placed at one side of a shutter or wall *fg*, the rays from which candles pass through the aperture, and are reflected on the wall at the points *h, i, k, l,* and *m*.

The sun in the early morning and again when departing in the evening, causes long shadows to be thrown from opake bodies; but when nearly vertical, at noon, the shadows are small.

An eclipse of the moon occurs by her passing through the long shadow of the earth, *i. e.* when the earth is between the moon and the sun.

Diminution of Light by Distance.

The rays of light diminish in intensity according to distance, in correspondence with the law that governs many forces, and radiating influences in general. Light diminishes as the square of the distance increases, in the proportion of 1, 4, 16, &c. to the distances 1, 2, 3, 4, &c. Its volume at the same time increases; for if a candle be lighted on a dark night and placed

in an open prominent position, the light will fill a sphere of a mile in diameter. The number of distinct rays must baffle all attempts at calculation; for were the entire space covered with eyes, all would receive a portion and become sensible of its presence. The various planets receive heat and light according to their distance from the sun's rays.

Reflexion of Light.

All bodies that are visible reflect light, in other words, cause a ray to turn back or rebound from their surface when it impinges upon them. It is by the entrance into the eye of these reflected rays that an object is seen. A perfectly transparent object would be invisible. Many transparent bodies, as glass and water, reflect a part of the light that falls on them. Water also absorbs a part. Anything that entirely absorbs light is opake and *black*. Anything that entirely reflects light is *white*, or destitute of colour. *Colours* are produced, as will be explained presently, by a breaking up of the ray of white light, of which a coloured body reflects a part and absorbs another part.

The law that regulates the line of reflexion is the same as that which applies to motion—the angle of reflexion is equal to the angle of incidence of the ray of light. With whatever obliquity the light strikes on a plane surface, with the same obliquity is it reflected from it in another direction. Most bodies have rough surfaces, made of an immense number of planes. These scatter light, by sending back the rays, so that they cross in all directions. Smooth or polished bodies have only one surface. This reflects light in one direction, so as to afford to the eye an image of any object before them. Of such surfaces, of metal or glass, are formed mirrors or specula. Persons standing before a looking-glass, see the figure of themselves apparently as far behind the glass as they are before it; this is from the ray having to travel from the person to the glass, then from the glass to the eye, and thus the distance is measured twice over, and the figure seems as far behind the glass as the figure in front is distant from it. Persons may see full-length figures of themselves in a glass which is not more than half the length of their bodies. Thus a young lady A B (fig. 182), anxious to see the effects of a new dress, standing before the looking-glass G *g*, will see its suit-

ableness at C D; for the ray passing from her eye falls per-

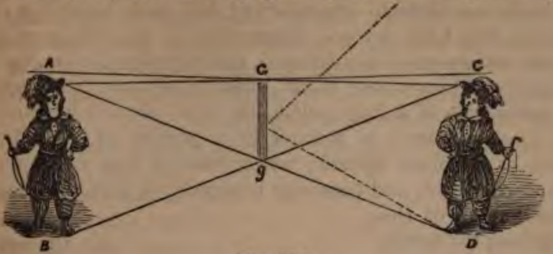


Fig. 182.

pendicularly on the mirror G g, and is reflected back in the same line to the eye, and has travelled through a distance equal to A G; but the ray proceeding from her feet B, which falls obliquely on the glass, will be reflected in the line g A to the eye; but as we view objects in the direction of the reflected rays which reach the eye, and the figure at the same distance behind the mirror as the person is before it, we must continue the line A g to D, and the line A G to C, where the figure is represented in the glass. The line g D is equal to g B or g A, and the line G g, which represents the length of the looking-glass, is half the line A B, which represents the height of the lady.

When we move backward from a looking-glass the figure seems to retire, and when we approach towards a glass the image seems to come forward; but with a velocity in both instances apparently twice that of your own movement, because the eye is affected with the motions both of the body and the image, which are equal and contrary.

Rays of light falling on glass pass through it, as we have shown; but when a coating of mercury is applied to one of the surfaces, the rays are arrested and reflected; thus then, it is not the glass but the mercury that reflects the rays which form the image. Had mercury not been fluid, it would have formed a better mirror without the glass than with it. The finest glass manufactured is not perfectly transparent, nearly half the light being either absorbed or irregularly reflected from the inaccuracy of the polish; this accounts for the image never being so bright as the object.

Few persons think, when they look at and feel glass, that

the surface possesses such an inequality as to make it reflect rays with considerable irregularity; but such being the case, opticians who have devoted themselves to the construction of superior astronomical instruments, and experimented on various substances, find a mixed metal, close in texture, little porous, and susceptible of a high polish, the best adapted for mirrors.

A concave mirror is formed of a portion of the internal surface of a hollow sphere; when parallel rays fall upon it, they are reflected, and converge to a point at half the distance of the surface of the mirror from the centre of its concavity.

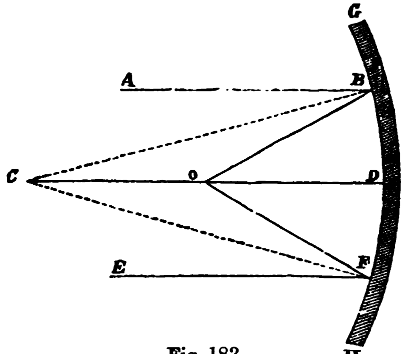


Fig. 183.

If the three parallel rays A B, C O D, E F (fig. 183) fall on the concave mirror G H, the middle ray will be reflected in a straight line D O C, as it is in the direction of the axis of the mirror. A B and E F, falling obliquely on the mirror, are reflected obliquely to O. Then O D will be found to be equal to O C, or the half of C D. The dotted lines, it will be observed, exactly divide the angles of incidence and reflexion, and the two oblique rays meeting at O make these angles equal. This, then, is the true focus at which parallel rays unite, for the more distant the rays the more obliquely they fall, the more obliquely are they reflected.

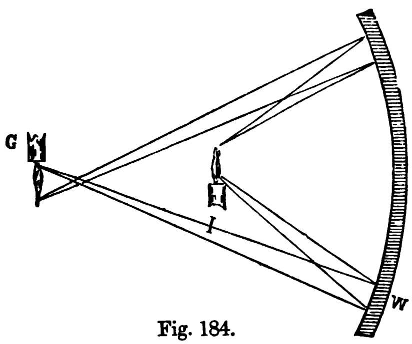


Fig. 184.

When a concave mirror is turned opposite a celestial object,

the rays proceeding from it are parallel to one another, and the image of the star, moon, or sun will be at O, half-way between the mirror and its centre of concavity; but the image will be an inverted one, as the rays cross each other. It is universally the case that the image formed by a mirror is inverted, if the rays after reflexion converge to an actual focus. Thus W (fig. 184) is the concave mirror, I the candle, and G the image of the candle inverted.

If, however, the candle be moved nearer to the mirror than the centre of concavity, then the image will not only be erect, but also magnified.

The diagram (fig. 185) illustrates the different effects of convergent and divergent rays on a concave mirror. When rays fall convergent, they are sooner brought to a focus, as seen in the full lines; but when divergent, as shown in the dotted lines, the focus is at a greater distance than with convergent or parallel rays.

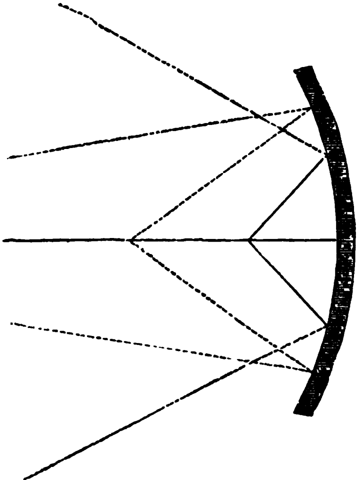


Fig. 185.

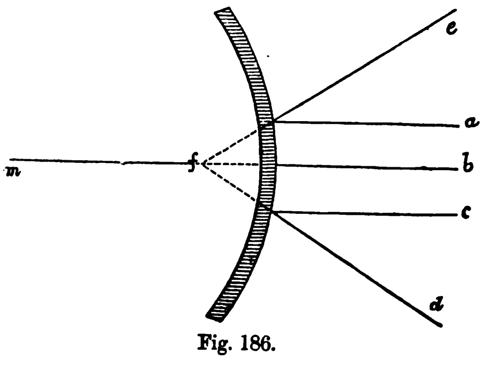


Fig. 186.

A concave mirror may then simply be said to magnify, because the rays coming from an object and falling on the glass appear to the eye placed in the focus to diverge to a great extent behind the glass when viewed in front.

A convex mirror is a part of the exterior surface of a sphere; and as the rays from it diverge, the images it produces are diminished. If three parallel rays *a b c* (fig. 186) fall on a convex mirror, *b*, being at the axis, proceeds straight onward to *m* the centre of the sphere; but *a* and *c* falling obliquely, are reflected obliquely to *d e*; now as all things are seen in the direction of the reflected rays, the image presented by this mirror would be the same as if it was placed at *f*, the focus of a concave mirror of the same spherocity.

A convex mirror diminishes the object, which invariably appears beyond the mirror, in its natural position, and smaller than the reality: the further the object is from the mirror, and the less the radius of the latter, the smaller will be the object, as in fig. 187.

Fig. 187.

An image thrown upon a mirror may, by employing more mirrors in an inclined position opposite each other, be multiplied many times and changed as often in every direction. To exhibit this there is an instrument made, called the magic perspective: it consists of a tube having a division through the middle; and the experimenter being told to place a book or piece of board in this division so as completely to obstruct seeing directly to the end, then to hold a coin or anything else at one end, and look through the other, is surprised, if uninitiated in the secret, at distinctly seeing the coin, as he supposes, through the book or board.

Let $a\,b\,c\,d\,e\,f\,g\,h$ (fig. 188) be the perspective tube, and $b\,f\,c\,g$ the opening in which the book or board is placed, i the eye, and k the coin. Then at $l\,m$ there is an opening into another tube $l\,n\,o\,m$; and at $l\,n\,o\,m$ are placed looking-glasses at angles

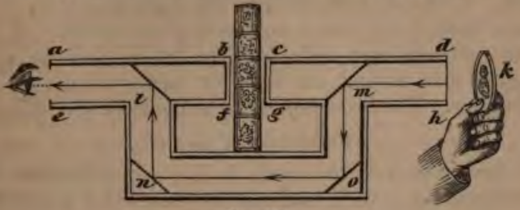


Fig. 188.

of 45 degrees with the side of the tube, and the reflected ray proceeds in the course of the arrows, and the reflexion of the image falling on m is again reflected to o, from o to n, from n to l, and from l to the eye, while all the time it appears to come in a straight line through the book.

A highly polished metallic concave mirror, when exposed to the sun, on collecting the rays to a focus, so concentrates the heat that it is designated a burning mirror, and possesses the properties of a burning-glass.

The Kaleidoscope.

When Sir David Brewster first exhibited the simple and beautiful little instrument named the *kaleidoscope*, it excited the attention of every one, and was as much the subject of conversation, interest and amusement in family circles as the *stereoscope* has become since. The kaleidoscope delighted from the variety, beauty, and arrangement of coloured artistic designs; presenting innumerable changes, that with the slightest movement "come like shadows and so depart;" the industrial decorator derived from it many valuable hints, and it was an endless amusement to youth. It consists of a tin tube about ten inches long and from two to three inches wide, blackened inside, and three pieces of looking-glass, or glass painted black on one surface; these are placed in the tube at an angle of 60 degrees. One end of the tube is covered with a cap having a small hole to look through; the other end has a piece of common window-glass, held in its place by a hoop of wire before and behind it. Another cap at the further end

has a piece of ground glass, and when fitted on there is a space of about a quarter of an inch between the common glass of the tube and the ground glass of the cap; in this space are placed coloured beads, pieces of glass, or other coloured transparent objects. This end being held to the light, and the eye at the opposite hole, the pieces of coloured glass between the angles of the reflectors are reflected five times, and a beautiful variegated star having six sides or angles meets the eye of the observer. The *Debusscope* is a kaleidoscope of another form.

Refraction of Light.

We have observed that opake bodies generally reflect light, and transparent bodies transmit it; but when a ray of light enters a transparent mass, that is, passes from one medium into another, in an oblique direction, the direction of the ray is changed both on entering and leaving: this is called ***refraction***. In the valuable treatise on this subject by Dr. Arnott, he remarks, "But for this fact, which to many persons might at first appear a subject of regret, as preventing the distinct vision of objects through all transparent media, light could have been of little utility to man. There could have been neither lenses as now, nor any optical instruments, as telescopes and microscopes, of which lenses form a part; nor even

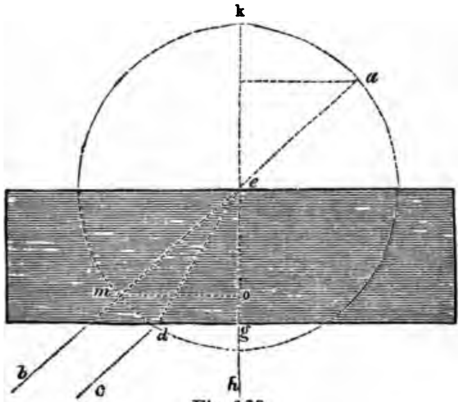


Fig. 189.

the eye itself." Rays of light falling perpendicularly upon a surface of glass or other transparent substances, pass through

without being bent from the original line of their direction. Thus, if a ray passes from *k* (fig. 189) perpendicularly to the surface of the piece of glass at *e*, it will pass to *h* in the right line *k*, *e*, *o*, *g*, *h*. But if the same ray be directed to the surface *e* obliquely, as from *a*, instead of passing through in a direct line to *b* in the direction *a*, *e*, *m*, *b*, it will be refracted to *d*, in a direction approaching nearer to the perpendicular line *k h*. The ray *a c* is termed the ray of incidence, or the incident ray; and the angle *a e k* which it makes with the perpendicular *k h* is called the angle of incidence. That part of the ray from *e* to *d* passing through the transparent medium is called the ray of refraction, or the refracted ray; and the angle *d e g* which it makes with the perpendicular is called the angle of refraction. The ray projected from *a* to *e* and refracted to *d*, in passing out of the transparent medium as at *d*, is as much bent from the line of the refracted ray *e d*, as that was from the line of the original ray *a e b*; the ray then passes from *d* to *c*, parallel to the line of the original line *a e b*. It follows, then, that any ray passing through a transparent medium, whose two surfaces, the one at which the ray enters and the one at which it passes out, are parallel planes, it is first refracted from its original course; but in passing out, is bent into a line parallel to and running in the same direction as the original line, the only difference being that its course at this stage is shifted a little to one side of that of the original. If from the centre *e* a circle be described with any radius, as *d e*, the arc *g m* measures the *angle of incidence g e m*, and the arc *g d* the *angle of refraction g e d*. A line *m o* drawn from the point *m* perpendicular to *h k* is called the *sine* of the angle of incidence, and the line *d g* the sine of the angle of refraction. From the conclusions drawn from the principles of geometry, it has been discovered by learned men, that when a ray passes from any one into any other particular transparent substance, the sine of the angle of incidence *m o* has always the same ratio to the sine *d g* of the angle of refraction, no matter what be the degree of obliquity with which the ray of incidence *a e* is projected to the surface of the transparent medium. If the ray of incidence passes from air obliquely into water, the sine of incidence is to that of refraction as 4 to 3; if it passes from air into glass, the proportion is as 3 to 2; and if from air into diamond, it is as 5 to 2.

"It is important to remark," says Dr. Arnott, "that for the same substance, whatever relation holds between the obliquity of a ray and the refraction in any one case, the same holds for all cases. If, for instance, where the obliquity as measured by its sine is 40, and the refraction is half or 20, then in the same substance an obliquity of 10 will occasion a refraction of 5, and an obliquity of 4 will occasion a refraction of 2, and so on. As a general rule, the refractive power of transparent substances or media is proportioned to their densities. It increases, for instance, through the list of air, water, salt, glass, &c. But Newton, while engaged in his experiments upon the subject, observed that inflammable bodies had greater refractive power than others; and he then hazarded the conjecture, almost of inspired sagacity, and which chemistry has since so remarkably verified, that diamond and water contained inflammable ingredients. We now know that diamond is merely crystallized carbon, and that water consists altogether of hydrogen, or inflammable air, and oxygen. Diamond has nearly the greatest light-bending power of any known substances, and hence comes in part its brilliancy as a jewel. No good explanation has been given of the singular fact of refraction; but to facilitate the conception and remembrance of it, we say that it happens as if it were owing to an attraction between the light and the refracting body or medium."

Vision defective through Refraction.

It ought always to be borne in mind "that we see every thing by means of the rays of light which proceed from it."

There is another axiom in optics to be remembered, which is, that "we see every thing in the direction of that line in which the rays approach the eye last." This is popularly illustrated by placing a piece of silver coin in an empty basin and retiring till the edge of the basin prevents it being seen; another person then pouring water into the basin gently, so as not to disturb the coin, it will come again into view of the person who retired from it. If the eye be at *g* (fig. 190) and the coin at *c*, when the basin is empty, the rays of light flowing from *c* must go in the direction of *c h g*, for then they cannot go in the direction of *h g*, the side of the basin preventing the eye from seeing the place of the coin *c*. But as soon as water is

poured into the vessel, the coin becomes visible by the refraction of the ray; it is not seen in the situation which it really

Fig. 190.

occupies, but an image of it higher up in the basin; for as objects appear to be situated in the direction of the rays which enter the eye, the coin will be seen in the direction of the refracted ray *g h e*. This also exemplifies that rays of light entering from a denser to a rarer atmosphere are bent from the direct line.

It is this deception on the vision that causes the bottom of a place in which there is clear water to appear nearer the surface than it really is. We may remark, however, this difference as regards the illustration we have given of the coin, that the formation of an image above the true place of the body does not depend on the situation of the eye; for when we look at the bottom of a clear river or pond perpendicularly, then it appears in its natural depth, because there is no refraction; but if we look in another direction, the rays which it reflects are refracted in their passage from the water into the air, which causes the bottom to appear nearer the surface, and consequently the water more shallow.

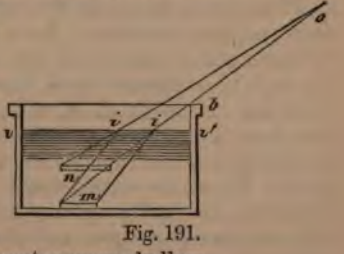


Fig. 191.

Thus we should not be able to perceive the object *m* in the vessel *v v′* (fig. 191), if the latter were empty, and the eye situated at *o*. Upon water being poured into the vessel, the rays passing from *m* to *i i* are refracted on emerging from the water, and the object will now appear to the eye to be at *n*, much higher than its real position.

A stick (fig. 192) plunged into water in any direction except the perpendicular will appear bent.

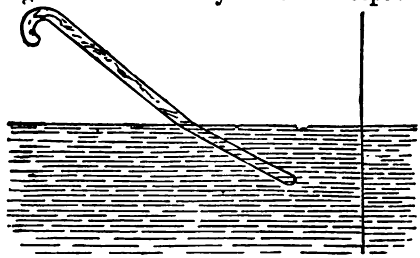


Fig. 192.

The angler when he dips his rod in the stream sees it twisted, and can only judge of its position from that portion which is out of the water.

The oars of a boat appear broken at the part that touches the water. The image of the position in the water seems apparently formed above the object itself.

In spearing salmon or eels the experienced fisherman allows for this deception of vision, as the sportsman calculates distance when he fires at a bird flying in the air.

Like every other provision of Providence for man, this refractive phenomenon is beneficial. When light leaves unknown space and enters our aërial atmosphere, it is refracted; and this prevents our seeing the heavenly bodies in their real position, seeming to be a little higher than they really are, excepting when directly over our heads.

Thus it is we do not see the sun and moon in the places where they really are situated. To a person on the earth at E (fig. 193), the sun, moon, or star that is at S appears as if at C, from the rays that proceed from S, entering the atmosphere surrounding the earth at R, being bent. The ray coming in a line from A to D seems to the eye to come from B, although in reality it comes from A, and is bent at D to the line ending at E. From this circumstance we see the image of the sun before the sun itself; and have added to the length of our days both the morning dawn and the evening twilight. Were it otherwise, we should suddenly pass from a glare of light into

intense darkness, which might be injurious to the eye, and produce many evils, of which, under the present wise and kind

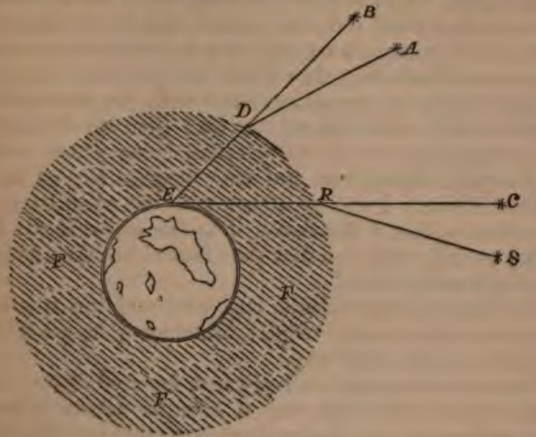


Fig. 193.

ordination, we are happily unconscious. If the sun were immediately over our heads, then the rays would proceed in a straight line without being refracted, and we should see it in its actual position, which is sometimes the case in the torrid zone. Still this must be remembered, that as we receive the ray of the sun eight and a quarter minutes after it has left its source, the sun must have shifted its position ere it is observed, therefore we see it at the place where it was when the rays left to proceed on their journey. In these remarks we have spoken of the apparent motion of the sun, produced by the diurnal rotation of the earth; but the effect would have been the same whether the sun or the earth moved, and hence we have referred to the subject as things seem to be.

A knowledge of the laws of refraction explains that which had often been a subject of wonder and fear to the ignorant, generally known by the term mirage, which is a reflexion or refraction of distant lands, cities, and vessels in the heavens. In some countries these appearances are of frequent occurrence, arising from the atmosphere between the eye and the object being more rarefied or dense in one part than in another.

Captain Scoresby relates that he once saw his father's ship inverted in the air when really it was below the horizon. The Captain says, "It was so well defined, that I could distinguish by a telescope every sail, the general rig of the ship, and its particular character, insomuch that I confidently pronounced it to be my father's ship, the 'Fame,' which it afterwards proved to be; though, on comparing notes with my father, I found that our relative position at the time gave our distance from one another very nearly thirty miles, being about seventeen miles beyond the horizon, and some leagues beyond the limit of direct vision. I was so struck with the peculiarity of the circumstance, that I mentioned it to the officer of the watch, stating my full conviction that the 'Fame' was then cruising in the neighbouring inlet."

The supposed supernatural appearance of the spectre ship known to sailors as the 'Flying Dutchman,' may perhaps be explained in some such way.

There are numerous well-attested facts of distant objects being seen close at hand, and of gigantic figures in fogs and mists, arising from a reflexion in the atmosphere. The following account of the singular phenomenon called the Spectre of the Brocken, in the Hartz Mountains in Germany, is given by Mr. Hane:—

"The sun arose about four o'clock, and the atmosphere being quite serene, towards the east his rays could pass without any obstruction over the Heinrichshöhe. In the south-west, however, towards Achtermannshöhe, a brisk west wind carried before it thin transparent vapours, which were not yet condensed into thick heavy clouds.

"About a quarter past four I went towards the inn, and looked round to see whether the atmosphere would permit me to have a free prospect to the south-west; when I observed at a very great distance, towards Achtermannshöhe, a human figure of a monstrous size. A violent gust of wind having almost carried away my hat, I clapped my hand to it by moving my arm towards my head, and the colossal figure did the same.

"The pleasure which I felt on this discovery can hardly be described; for I had already walked many a weary step in the hopes of seeing this shadowy image, without being able to gratify my curiosity. I immediately made another movement

by bending my body, and the colossal figure before me repeated it. I was desirous of doing the same thing once more, but my colossus had vanished. I remained in the same position, waiting to see whether it would return, and in a few minutes it again made its appearance on the Achtermannshöhe. I paid my respects to it a second time, and it did the same to me. I then called the landlord of the Brocken; and having both taken the same position which I had taken alone, we looked towards the Achtermannshöhe, but we saw nothing. We had not, however, stood long, when two such colossal figures were formed over the above eminence, which repeated our compliments by bending their bodies as we did, after which they vanished. We retained our position, kept our eyes fixed on the same spot, and in a little time the two figures again stood before us, and were joined by a third. Every movement we made by bending our bodies, these figures imitated, but with this difference, that the phenomenon was sometimes weak and faint, sometimes strong and well-defined. Having thus had an opportunity of discovering the whole secret of this phenomenon, I can give the following information to such of my readers as may be desirous of seeing it themselves.

"When the rising sun—and according to analogy the case will be the same as the setting sun—throws his rays over the Brocken upon the body of a man standing opposite to fine light clouds floating around or hovering past him, he need only fix his eyes steadfastly upon them, and in all probability he will see the singular spectacle of his own shadow, extending to the length of five or six hundred feet, at the distance of about two miles before him."

Lenses.

We now come to the account of those useful optical instru-

Fig. 194.

ments, the proper construction of which gives them value, and

which are called lenses. They consist of glass ground to particular forms (fig. 194), best suited to collect and disperse rays of light. The effect of any lens upon the ray of light may always be discovered, if it be borne in mind that on entering glass from air the ray is bent *towards* the perpendicular to the surface, and on emerging into air from glass, it is again bent *from* the perpendicular to the surface.

A plano-convex lens (fig. 195) has one side flat, and the other, *b c*, convex. The axis of a lens is a line passing through its centre, as *a d*. When rays approach each other to meet at one spot, they are said to converge; thus the parallel rays B B B B (fig. 196) passing through the plano-convex lens D, converge until they meet at C; if the light were reversed, and C was a candle, then the rays would, as it were, retreat from each other in approaching the lens, and be said to diverge. C is termed the focus of the lens D,

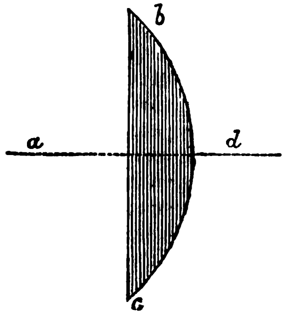


Fig. 195.

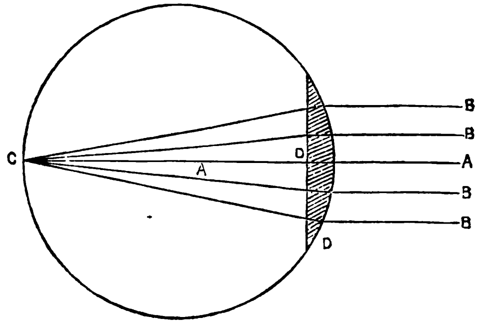


Fig. 196.

for the parallel lines passing through it all meet there. The distance of the focus from the centre or middle of the glass may be known by drawing a circle around it, as it is equal to the diameter of the sphere of which the convex surface forms a part. Rays of light passing out of a rarer to a denser

medium incline to the perpendicular to the surface, so that the rays B B B B passing through the lens bend to the axis or pendicular ray A C. C is also called the principal focus, or the focus of parallel rays, and its distance from the middle of the glass is the focal distance.

A plano-concave lens, *b c* (fig. 197), is flat at one side and concave at the other; and the parallel rays diverge after passing through it, as if they had come from a radiant point, at the distance of the diameter of the concavity of the lens: this is called the imaginary focus. Thus the rays *e e* (fig. 198) are refracted to *e′e′*, as if they had proceeded from the point *e*.

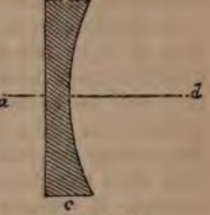


Fig. 197.

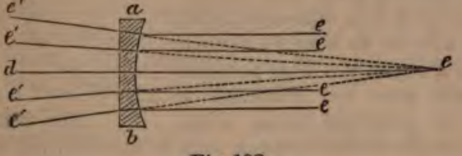


Fig. 198.

A double-concave lens (fig. 199) is concave at both sides. When parallel rays of light fall upon it, instead of converging to the parallel ray, they seem drawn to the lens, and diverge from the parallel ray both in their passage through the lens and afterwards upon leaving it. The imaginary focus is at the distance of the radius of concavity.

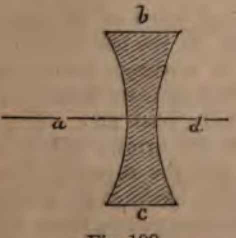


Fig. 199.

Fig. 200.

A meniscus lens (fig. 200), or moon-shaped, is convex at one

side $b\,c'$, and concave at the other $e'\,e$; its effect is according to the manner in which it is applied. With regard to this, as well as other lenses formed of glass, the angle of incidence always bears the same ratio to the angle of refraction, whether it be with regard to plane or spherical surfaces, concave or convex, or in whatever direction the rays may be refracted.

A double-convex lens is convex on both sides. If parallel rays of light fall directly upon a double-convex lens A (fig. 201), they will be so bent out of their course as to unite in a point at *f*. The central ray, falling perpendicularly upon the glass, passes directly through it without suffering any refraction; but those which pass through further from this centre, falling more or less obliquely on its surface, will be so bent as to meet the central ray at *f*. This point, at which the rays are collected, is termed the principal focus, whose distance in the double-convex lens is equal to the radius, or half the diameter of the sphere of the convexity of the lens.

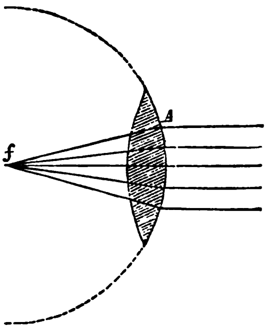


Fig. 201.

If rays are made to traverse a double-convex lens, they must converge more rapidly than through a plano-convex one, for they are first refracted at the convex surface of a denser medium on entering the lens, and are again refracted at the concave surface of the rarer medium in passing again into the air, and must therefore have a double degree of convergency. It is likewise seen in fig. 202 that if an object $a\,b$ be placed beyond the focus of a convex lens $e\,f$, some of the rays proceeding from the point of the object on the other side of the glass will, after passing through it, converge into as many points on the opposite side; $a'\,b'$, which proceed from the point a, will converge into $a'\,b'$, and finally meet at c. The rays $c'\,d'$ proceeding from the middle of the arrow, will be conveyed into $c''\,d''$ and meet at g; and the rays which come from the point b, will meet each other again at d; and so on of the rays from any of the intermediate points, there will be as many focal points formed as there are radial points in the object, and consequently they will be painted on the retina of

the eye, a sheet of paper, or any other body placed at *d*, *g*, *c*, as an inverted image of the object.

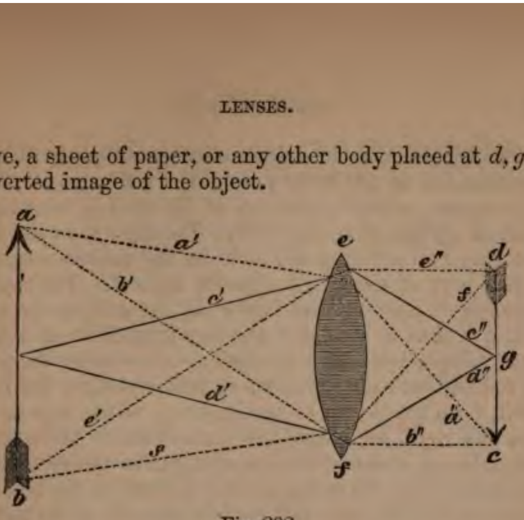


Fig. 202.

If a convex lens be placed in the hole of the shutter *g* (fig. 203) of a darkened room, it will concentrate the rays of light, and represent on the opposite wall a picture of the different objects from which the rays proceed, but in an inverted position.

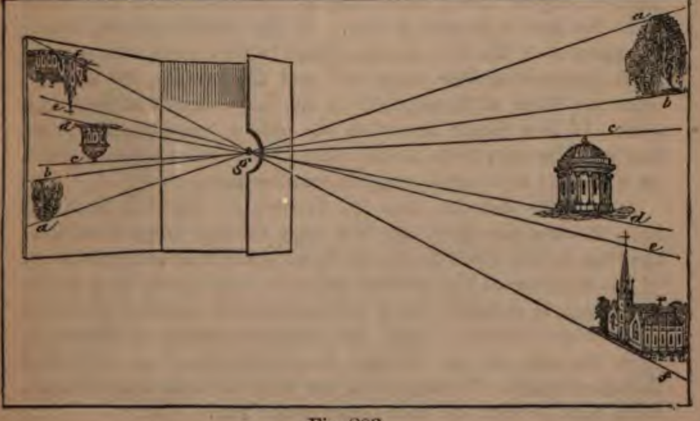


Fig. 203.

The rays from the top of the tree *a* proceed onward and are represented at *a*; the rays of light moving in a straight line

and entering the room in a descending direction, by their thus continuing, fall on the lower part of the wall opposite the hole in the shutter, whereby the top of the tree is seen inverted instead of upright as in the view. The rays from the bottom of the tree *b* on entering the hole in the shutter ascend, and thus this part of the tree *b* appears highest. The rays from the church *e f* represent its figure on the wall in the manner *e f*. It will thus be seen that the rays from different directions proceed independently in a straight line, reversing the position from the highest to the lowest; or the rays from the right to the left, from the lowest to the highest; or the rays from the left to the right, excepting the mausoleum in the centre *c d*, which although upside down, its situation in the picture is the same: this is from its being exactly in front of the hole in the shutter; and as its rays fall perpendicularly, so do they proceed to the wall. In fact, the whole is an inverted miniature representation of the landscape; and is exactly the same principle on which the pupil of the eye portrays objects on the retina, and on which the camera obscura acts.

The diagram (fig. 202) shows also that the image of an object seen through a convex lens will be larger or less than the object itself, according as the distance of the latter from the lens is greater or less. If the smaller arrow, which is placed near the lens, be the object to be viewed, the rays of light, proceeding from each end and the middle, are seen to come to a focus at three points in the larger arrow at the other side. If this larger arrow be the object, being further from the lens, the rays from it will come to a focus at a nearer point on the other side, producing the smaller image.

It is to be observed that the further an object is from the lens, the less divergent are the rays darting from it towards the lens, or the more nearly do they approach to being parallel. If the distance of the radiant point be very great, they really are so nearly parallel that a very nice test is required to detect the non-accordance. Rays, for instance, coming to the earth from the sun, do not diverge the millionth of an inch in a thousand miles. Hence, when we wish to make experiments with parallel rays, we take those of the sun.

Any two points so situated on the opposite sides of a lens, as that when either becomes the radiant point of light, the other is the focus of such light, are called *conjugate foci*. An

object and its image formed by a lens must always be in *conjugate foci*; and when the one is nearer the lens, the other will be in a certain proportion more distant.

What is called the principal focus of a lens, and by the distance of which from the glass we compare or classify lenses among themselves, is the point at which the sun's rays, that is, parallel rays, are made to meet; and thus, by holding the glass in the sun, and noting at what distance behind it a little luminous spot or image of the sun is formed, we can at once ascertain the focus of a glass.

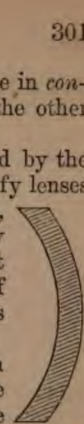


Fig. 204.

A concavo-convex lens (fig. 204) is one in which the two surfaces agree in general form with the meniscus lens, but differ in this respect, that the concave surface is a part of a smaller sphere than that of the convex side; the two surfaces, if produced, would never meet as they do in the meniscus.

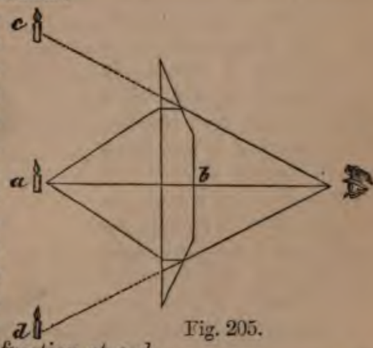


Fig. 205.

A multiplying-glass is a convex lens having a number of faces cut at angles to each other upon it, so that objects seen through it are multiplied. Thus the rays from a candle or other object from *a* to *b* (fig. 205) are refracted in passing through the glass, so that the eye where they meet sees three objects, one direct at *a*, and two by refraction at *c*, *d*.

We may here state that what is understood by a pencil of rays, is when rays *a a* (fig. 206) diverge or spread out from a single point of a luminous body *b*. A ray is always intended to signify a single line of light proceeding from a luminous object.

Either a double-convex or plano-convex lens, it is seen, will refract the rays of the sun falling on its surface to a point on the opposite side; as any such constitutes a burning lens, the point to which they arrive is hence called the *focus*. The larger the surface, the more powerful will be the focus: sup-

pose a lens four inches diameter have a focus at one foot

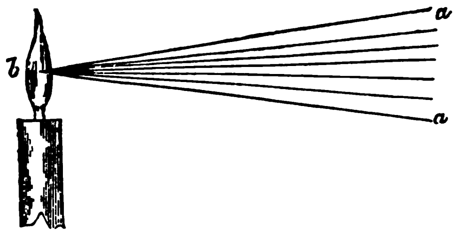


Fig. 206.

distance, giving an image of the sun the one-tenth of an inch in diameter, 1600 times less than the surface, consequently the rays at the focus will be this much denser than at the surface. A very powerful burning lens was made by Mr. Parker for Dr. Priestley, and was or is in the possession of the Emperor of China. Fig. 207 represents it as mounted on a stand. It was formed of flint-glass nearly three feet in diameter, having when fixed a clear surface of two feet eight inches and a half; its weight was 212 pounds, its focal length six feet eight inches, and the diameter of the image of the focus one inch; but by applying another lens, the focus was reduced to half an inch in diameter. It produced a heat that set fire instantly to hard, green, or wet wood; it melted iron plates in a moment; and tiles, slates, and earths became vitrified. Sulphur, pitch, and all resinous bodies melted under water; fir-wood exposed to the focus under water did not seem changed, but when broken,

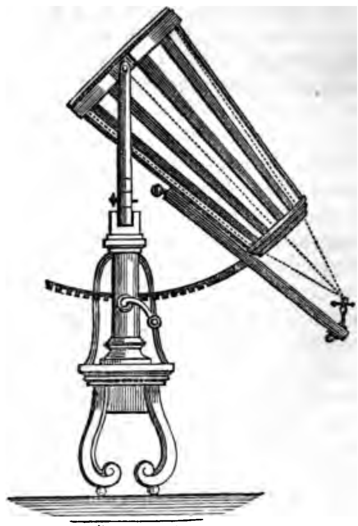


Fig. 207.

the inside was burnt to coal. If a cavity was made in a piece of charcoal, and the substances to be acted on were put in it, the effect of the lens was much increased: any metal thus enclosed in the cavity of a piece of charcoal melted instantly, the fire sparkling like that of a forge; the ashes of wood, paper, linen, and all vegetable substances were turned into a transparent glass. The substances most difficult to be wrought on were those of a white colour. It fused twenty grains of gold in four seconds; of silver in three seconds; ten grains of platinum in three seconds, and as much flint in thirty seconds; yet there was no heat at a small distance out of the focus. The finger could be placed in the cone of rays, within an inch of the focus, without any hurt: when Mr. Parker placed his finger at the focus, he said it did not feel like ordinary burning, but the sensation was that of a sharp cut with a lancet. The water when clear, and in a clean glass decanter, was not even warmed; but with iron in it, or ink, it was made to boil.

Camera Obscura.

A camera obscura consists of an oblong box in one end of which is fitted a smaller portion having a convex lens, and which part slides in or out to adjust the focus according to the distance of the external objects. At the opposite end of the box, at an angle of 45 degrees, a plane mirror *p i* (fig. 208) is

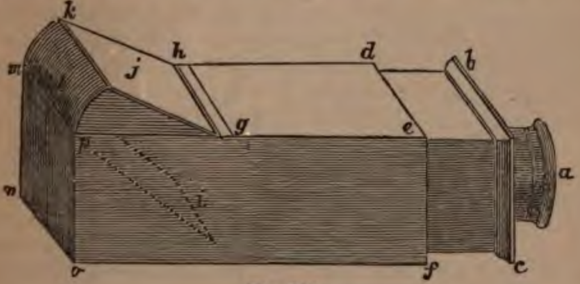


Fig. 208.

fixed, which receives the image of the object from the lens *a*, and reflects it against a square of ground glass *j*. The picture there represented may be sketched on the rough glass, or if a piece of oiled or tracing paper be laid on it, a copy may be taken;

but to do this effectually, a black cloth should cover the head and end of the camera to exclude extraneous light. This instrument has acquired of late an additional importance by its use in photography. The picture to be photographed is first focused on the ground glass, and a sensitive plate being now substituted for it for a brief space of time, the required picture is impressed upon it by the sunbeam.

Prisms.

A prism is a solid body included between three or more faces, each of these being a parallelogram. A triangular prism of glass possesses the property of bending the rays of light from their original course by refraction. Thus

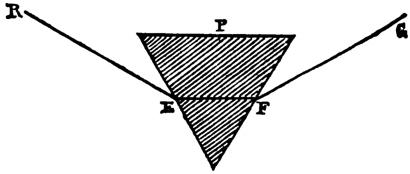


Fig. 209.

the ray R E (fig. 209) entering the prism P at the point E is refracted in the direction of the line E F, and on leaving the prism at F is again refracted in the direction F G; but all the rays constituting white light are refracted in a different degree, as will be afterwards explained.

In the diagram (fig. 210) the faces of the glass prism are

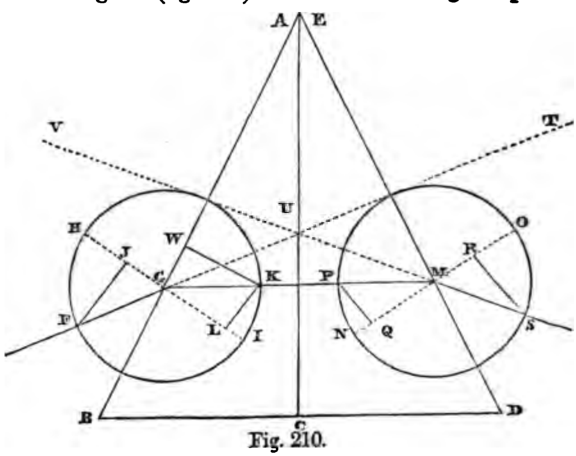


Fig. 210.

A B and D E, and if of crown glass will have a refractive power of 1·525. Now if a ray of light, F G, fall on the face of the prism at G, draw a line H I perpendicular to the face A B, then with a pair of compasses from a scale of equal parts take the refractive power 1·525; then place one point of the compasses on G F, move it along to some point F, till the other point falls on a point J of G H, so that F J is perpendicular to G H; then with G as a centre, with the distance G F describe the circle I F H. On the scale before-named with the compasses take 1·000 and set it off from G towards A; this will give the point W; through this point draw W K parallel to H I; then from the point K, where this line cuts the circle, draw K L perpendicular to H I. Thus, then, F J is the sine of the angle of incidence, and L K the sine of the angle of refraction, and the line G K M drawn through K represents the refracted ray.

Then as the ray G M meets the second refracting surface at M, through it draw N O perpendicular to E D, and with M as a centre, and distance G F, describe a circle and construct the figure P N S O, exactly similar to the one above described.

The ray departing from the prism into the air in this last instance, P Q is the sine of the angle of incidence, and R S the sine of the angle of refraction, therefore the line M S drawn through M will be the refracted ray. It will be seen that the prism, from its powers of refraction, has bent the ray, which if not refracted would have proceeded direct onward to T, and gives the angle T U S as the amount of the deviation from a direct line. Now if a ray of light fall on the face of the prism at F G, by looking at S, it will be seen at V proceeding along the line M U V, and the angle V U F will be equal to the angle T U S.

On the refracted ray G M traversing the prism, it proceeds in a direct line parallel to B D; and on this occurring, the angle of deviation F U V is not so great as if the ray fell in any other position, or the prism were differently constructed. If a candle be used to give the ray, then by looking at M of the prism and turning it round, the image of the candle will be stationary at V, which shows the line G M is parallel to B D; but in any other position the image will move towards V.

If a line be drawn from A E to C, so as to divide the base of the prism into two equal parts, when in the position as represented in the diagram, then the angle of refraction K G L on the

surface of the prism where the ray enters is equal to B A C, half of the angle of the prism. Then as half this angle has been ascertained, and as it is easy by a dividing instrument to measure the angle of incidence, F G H is at once known, as well as the angle of refraction O M S on the other surface of the prism; and having ascertained them on one side, they are easily known on the other. Then dividing the sine of the angle of incidence by the sine of the angle of refraction, the refractive power is gained.

Analysis of the Ray of Light.

If a prism be placed opposite to a hole in a shutter admitting a ray of light to a darkened room, a singular effect takes place, for an explanation of which we are indebted to Sir Isaac Newton; it shows us that the pure ray of white light is composed of several brilliant colours. In old times light was considered to be a simple homogeneous body. But if the ray be transmitted through the prism, and thrown on a screen opposite, seven distinct colours will appear in the following order (fig. 211):

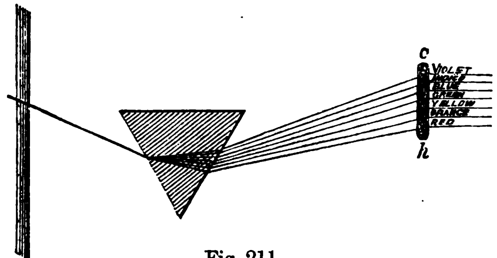


Fig. 211.

This dissection of a ray of light, then, shows it to be composed of red, orange, yellow, green, blue, indigo, and violet colours. The red rays, it will be observed, are the least turned out of their course, and the violet the most so; and the others possess this property more or less as expressed on the screen where they are represented: the breadth of the oblong image of the colours is equal to the diameter of the hole in the shutter. It is a curious coincidence, that the number of colours agrees exactly with the primitive number of notes in music.

Supposing the division on the *prismatic spectrum*, as the image of the ray on the screen is called, be divided into 360 parts, the proportion of the red will be 45 parts, the orange 27, the yellow 48, the green and blue 60 each, the indigo 40, and the violet 80. If a circular piece of card be divided into these proportions and coloured accordingly, then whirled rapidly round, the colours will be so blended as to appear of a dirty white; were the colours as pure as those painted by nature, there can be no doubt but that the appearance would be a perfect white. But the most convincing proof that those colours constitute a pure white ray is by reuniting them. Thus if the coloured rays are allowed to fall upon a double convex lens L (fig. 212), they pass through it and converge to a focus,

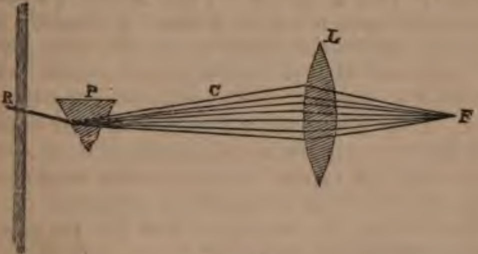


Fig. 212.

when they appear as a white ray the same as before passing through the prism. The ray R entering the hole in the shutter falls upon the prism P, and is separated into the seven colours C, which passing through the lens L, unite in a white ray at the focus F. Thus is the ray separated and again joined into its former body.

The solar or prismatic spectrum is only at particular parts vivid as to each distinctive colour, for they mingle and blend the one into another in such a manner as to render it impossible to say where each begins or ends. The seven colours have been named primary, it being believed that they are simple or homogeneous, especially as when reflected through another prism they retain their individuality. Artists, nevertheless, have proved that red, blue, and yellow will alone form all the tints of the prismatic spectrum; supposing that the other colours were heterogeneous, or compounds. Still, as the colours

refracted could not be analysed into others than they appeared, a difficulty existed that prevented the fact being established of their not being primary colours. Many have been the experiments made by scientific persons to solve this question satisfactorily; and Sir David Brewster and others have concurred in the opinions of Mr. Hay of Edinburgh, as expressed in his work on the 'Laws of Harmonious Colouring.' Mr. Hay states that he could not by analysis prove that there were only three colours, but that he succeeded in proving it to his own satisfaction, synthetically, in the following manner:—

"After having tried every colour in succession, and finding that none of them could be separated into two, I next made a hole in the first screen in the centre of the blue of the spectrum, and another in that of the red; I had thereby a spot of each of these colours upon a second screen. I then, by means of another prism, directed the blue spot to the same part of the second screen on which the red appeared, where they united and produced a violet as pure and intense as that of the spectrum. I did the same with the blue and yellow, and produced the prismatic green; as also with the red and yellow, and orange was the result. I tried, in the same manner, to mix a simple with what I thought a compound colour, but they did not unite; for no sooner was the red spot thrown upon the green than it disappeared.

"I tried the same experiment with two spectra, the one behind, and of course a little above the other, and passed a spot of each colour successively over the spectrum which was furthest from the window, and the same result occurred. It therefore appeared to me that these three colours had an affinity to one another that did not exist in the others, and that they could not be the same in every respect except colour and refrangibility, as had hitherto been taught."

The three homogeneous colours, yellow, red, and blue, have been proved by Field, in the most satisfactory manner, to be in numerical proportional power as follows:—yellow, three; red, five; and blue, eight. When these three colours are reflected from any opake body in these proportions, white is produced. They are then in an active state, but each is neutralized by the relative effect that the others have upon it. When they are absorbed they are in a passive state, and black in the result. When transmitted through any transparent

body, the effect is the same; but in the first case they are material or inherent, and in the second impalpable or transient. Colour, therefore, depends entirely on the reflective or refractive power of bodies, as the transmission or reflexion of sound does upon their vibratory powers.

If a delicate thermometer be placed in different parts of a prismatic spectrum, the violet rays indicate the least heat, but the mercury gradually rises as we descend downwards, the red having the most; passing below the red ray, it was found a greater degree of heat existed, and that in that part there is a ray which is invisible; this has been named the calorific or heating ray. Led from this circumstance to experiments above the violet ray, another invisible ray was discovered to exist, with less heat, but possessing the property of changing the chloride of silver from white to black, and gum guaiacum from yellow to green; this is termed the chemical or actinic ray, the rays between these invisible ones being denominated the colouring or colorific rays. Now if a body giving out these invisible rays that are less bent than the red ones of the spectrum, be much heated, its rays may be as much bent as the red ones, and may then be seen, the radiating body being red-hot. More heat applied causes yellow rays to be seen, and ultimately the whole of the colours as white heat; thus some writers have come to the conclusion that heat is invisible light, and light visible heat.

It has been found that beyond the visible spectrum in both directions there are rays which excite no impression of light. Those at the red end excite heat; and the reason why they fail to excite light probably is that they never reach the retina of the eye. To show this, a thermo-electric pile was placed near the red end of the spectrum, but still outside of it; the needle of a large galvanometer connected with the pile was deflected, and came to rest in a position about 45 degrees from zero. The transparent humours of the eye of an ox were now placed in the path of the rays; the light of the spectrum was not perceptibly diminished, but the needle of the galvanometer fell to zero; thus proving that the obscure rays of the spectrum, to which the galvanometric deflection was due, were wholly absorbed by the humours of the eye. For this discovery we are indebted to Sir William Herschel.

To prove this experimentally, take an opake screen A B

(fig. 213), blacken both sides; at C make a round hole about

Fig. 213.

half an inch in diameter; directly opposite to which place I a hot iron ball, D a thermo-pile in connexion with a galvanometer; the rays of heat from I will pass through the aperture C, and falling on the pile D will deflect the galvanometer. If an ox-eye be now adjusted to and accurately fill up the aperture C, no heat will pass, and the galvanometer remains stationary; thus proving that the aqueous and vitreous humours of the eye oppose the passage of the rays of obscure heat.

Theory of the Ray of Light.

The undulatory hypothesis accounts for the differently-coloured rays of the solar spectrum, by supposing differences in the frequency of the vibrations. The rays of light are supposed capable of vibrating in waves of different lengths; the shortest waves produce violet light, the longest red. The impression of the different colours arises precisely as that of the different sounds in air; the shortest wave in sound gives the highest note.

With such precision have some of the more complex phenomena of light been studied, that mathematicians have absolutely been able to calculate the number of vibrations (in ether) necessary to produce an impression of white or coloured light.

The periodical movements of the medium in white light regularly recur at equal intervals, five hundred millions of millions of times in a second of time—1,000,000,000,000 × 500; in the sensation of redness, our eyes are affected four

hundred and eighty-two millions of millions of times—1,000,000,000,000 × 482; of yellowness, five hundred and forty-two millions of millions—1,000,000,000,000 × 542; of violet, seven hundred and seven millions of millions—1,000,000,000,000 × 707.

Sir John Herschel gives the following as the length and rapidity of the coloured rays of the spectrum:—

Coloured rays.	Length of luminous rays in parts of an inch.	Number of undulations in an inch.	Number of undulations in a second.
Red	·0000256	39180	477 millions of millions.
Orange. . .	·0000240	41610	506 "
Yellow. . .	·0000227	44000	535 "
Green . . .	·0000211	47460	577 "
Blue . . .	·0000196	51110	622 "
Indigo. . .	·0000185	54070	658 "
Violet . . .	·0000174	57490	699 "

Taking, therefore, the ratio of the extreme vibrations, we may say, the sensibility of the eye has its limits within a minor sixth, while that of the ear reaches an octave.

How seldom do we think, as we gaze on the flowers composing a bouquet, and inhale their fragrance which fills the surrounding air, that in order to distinguish the yellow tint of the laburnum, five hundred and forty-two millions of millions of vibrations must occur; that the ruby fuchsia requires the eyes to receive four hundred and eighty-two millions of millions of undulations in a second; that the violet's tint is only distinguishable when seven hundred and seven millions of millions of vibrations have penetrated to the retina!

What marvellous mechanism, then, must pervade nature, since we can see in the momentary flashing of the eye the innumerable and varying hues with which the earth is carpeted, the birds gorgeously plumed, and the slightest variation in the races of animals and the features of man!

Fraunhofer's Bands.

Certain dark lines or bands are observed on the spectrum, which are supposed to be owing to the fact of the solar atmosphere having the property of absorbing particular portions of the rays of light. These lines, which are called Fraunhofer's,

after their discoverer, are somewhere about 600 in number. They do not follow each other with any degree of regularity, but the same position is always retained in the same kind of light: but they differ in size, number and arrangement, in light obtained from different sources; hence it would appear that every luminous body has a system of light peculiar to itself. These dark lines in the spectrum were used by Fraunhofer for accurately measuring the refraction, the breadths of the individual colours, and the intensity of the light of luminous bodies. According to Fraunhofer's measurement, the relative intensities of the light of the different portions of the spectrum expressed numerically the luminous intensity of the extreme red ray to be 32; of the middle ray of that colour, 94; of orange, 640; between yellow and orange, 1000; green, 480; blue, 170; dark blue (indigo), 31; violet, from 5 to 6.

Nature of the Sun's Ray.

Professor Hunt, who has devoted much time to the investigation of the influence of the solar rays, says, "We have been hitherto led to regard the sun's rays as consisting essentially of light and heat; and these, indeed, were commonly considered as modifications of one power. Melloni has, however, shown that plates of obsidian and black mica, which do not admit of the permeation of light, are freely penetrated by heat; and, on the contrary, that a glass stained green by oxide of copper, which offers scarcely any obstruction to light, will scarcely allow of the passage of any heat-rays. In this way it is distinctly shown that the physical conditions of these forces are essentially different; and, in a similar manner, we may entirely obstruct the chemical agency by the use of a yellow glass, while a blue medium, which obstructs nearly all the light, admits of the free passage of the chemical radiations.

"In this manner we are made acquainted with the existence of certainly three physical agents in the solar beams—light, heat, and actinism, as the chemical power is called. Their existence may be shown in the following manner:—If we pass a sunbeam through a glass prism, we get a coloured luminous image, *a* (fig. 214), consisting of seven chromatic bands. If we throw the same image upon black paper washed with ether, an image rapidly dries in the forms shown in *b*,

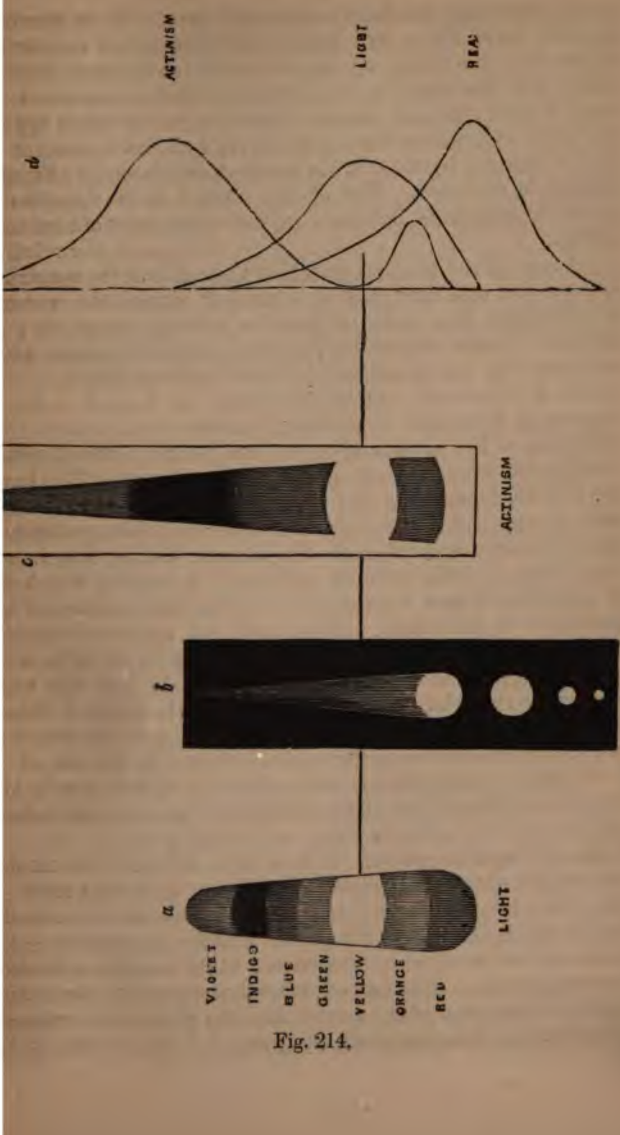

ACTINISM
LIGHT
ACTINISM
HEAT
LIGHT
VIOLET
INDIGO
BLUE
GREEN
YELLOW
ORANGE

Fig. 214.

which represents the heat's rays, and proves the existence of calorific rays, which are entirely without light; and if we throw the same image on paper covered with the chloride of silver, it is blackened in the manner shown at *c*, in which the most decided chemical change is observed to take place beyond the violet ray, where there is no light; and that in the yellow ray, where the light is at its greatest intensity, no chemical change is produced. The curved lines *d* show the relative points of maximum influence in the solar spectrum for each power.

"From all the phenomena which these solar powers exhibit, it is evident that they exist in a state of antagonism, and one is sometimes in a state of superior activity compared with another. Seeds require an excess of actinism to germinate; and they will not germinate in light from which the actinic power is separated. After the leaves are formed, a larger amount of light than of actinism is necessary to produce that excitation of the cellular system of the plant by which carbon is separated from carbonic acid, and wood produced. Again, the full development of the reproductive system of the plant, its flowering and fruiting, depends upon an influence which is more closely connected with the thermic power of the sun's rays, than on either light or actinism. A very curious series of experiments has been made to prove that seeds will not germinate in pure light. Plants will not form wood in unmixed actinic radiations, nor will they flower in either light or actinism separated from the heat-rays. It has also been found that the relative proportions of light, heat, and actinism vary in the seasons of spring, summer, and autumn, which is in exact accordance with the results obtained by experiment.

"Thus so beautifully has nature disposed of the constitution of the solar beams, that these antagonistic powers are balanced one against the other in exact accordance with the requirements of organic nature. It has been discovered that the proportions of these principles are different in various parts of the globe; light and heat being at a maximum at the equator, and diminishing towards the poles; whereas actinism is at its minimum at the equator, and arrives at its maximum in the temperate zones. This fact explains the cause obviously of the gigantic vegetation of the tropics, and the gradual dwarfing of plants as we proceed towards the pole.

"Indeed, it may be proved by simple experiments that the sun's rays cannot fall upon any body, whether it be of metal, of wood, of stone, or of glass, without producing a disturbance, either molecular or chemical, on its surface; also that all bodies in nature have the power of restoring themselves during the hours of darkness to the state they were in previous to the solar disturbance. May we not hence infer that darkness is as necessary to the inorganic oody, as night and sleep to living and breathing beings? These researches, which have arisen from the discovery of photography, have already led to the elucidation of many mysteries connected with the great phenomena of nature; and the discovery of the new element *actinism* promises to lead us rapidly forward in our examinations of the secret powers of creation."

Colours of Bodies.

It is now a generally received opinion, that different bodies, according to the manner in which their minute particles are arranged, have the power of variously absorbing and reflecting the rays of light; and that on the proportions of the rays absorbed and reflected does the colour depend, and that it is not a part of the object itself. Herbage appears to absorb all portions of the ray except green; this it reflects, therefore herbage seems to the eye of a green colour. A heartsease differs in texture when its flowers vary in colour. A poppy appears scarlet, as it absorbs all the colours of the rays except red, and hence its peculiar tint; but if it be held under green glass it will appear black, as the poppy only reflects the red ray which the green glass absorbs. The red of the rose, the blue of the violet, the yellow of the jonquil, are owing to their absorbing all the rays excepting the red, blue, and yellow. A white colour is the reflexion of all the rays; a black is caused by their entire absorption. The palely tinted rose, almost white, reflects nearly all the coloured rays. Without light, the face of nature would be that of a world in mourning; it is light that enlivens the scene, painting the exterior with a beauty, richness, delicacy, and harmony, that man vainly attempts to rival.

Colour is so dependent on light, that when artificially produced, as by candle or gas, from not being so pure as the rays of the sun, many things appear of a different colour, as is well

known by the lady who chooses a ribbon, or the artist who attempts to paint a picture by artificial light; a blue being mistaken for a green, and a green for a blue. Thus sometimes an artist has been surprised to find he has made the sky green and the grass blue. On a moonlight evening we cannot distinguish the colour of a chimney-pot; and were we to take a number of pieces of different coloured papers, examine them by the bright light of the moon, and write on the back of each the colour it appears, we should be astonished in daylight to see how much we had been deceived as to the true tint of each. If vermilion, powder-blue, and light chrome-yellow be intimately mixed, without rubbing, and the powder be allowed to fall in a stream in the sunshine, it will appear white.

If the top of a humming or peg-top be painted with red, blue, and yellow, and it be made to spin with velocity, the colours will be lost to the sight, and a white be seen, if the colours be proportioned in the manner heretofore described.

There have been persons of defective vision who could not distinguish particular colours. Dr. Darwin, the poet and botanist, could only by shape discover the difference between a cherry and the leaves among which it grew. Dr. Dalton, the celebrated chemist, was similarly afflicted. There was also a family at York who had this peculiar defect of colour-blindness hereditarily.

Sometimes a body will transmit one kind of colour but reflect another; thus there is glass that transmits orange but reflects green. Again, it may be observed that some colours will only be observable if the material be of a certain thickness, beyond which all colour is lost, and blackness only to be seen. Leaf-gold transmits yellow, but reflects a greenish blue.

Sir Isaac Newton found that different colours required different distances to bring them to a focus. He placed two candles at about twice the focal length from a double-convex lens L (fig. 215), interrupting the light by a piece of red and blue glass R B, when it was found that the images B R, R B on the screen *s* partook of the colours of the glass employed. By placing another screen D nearer to the lens, then the red figure was perfect on D; thus the focus for different colours was found to be at different distances from the lens, and the images were more distinct with coloured glasses than without. Thus it is that we are able to read a blue or red bill through a

telescope more easily than a white bill, and have to lengthen the telescope more to read a red bill than a blue one.

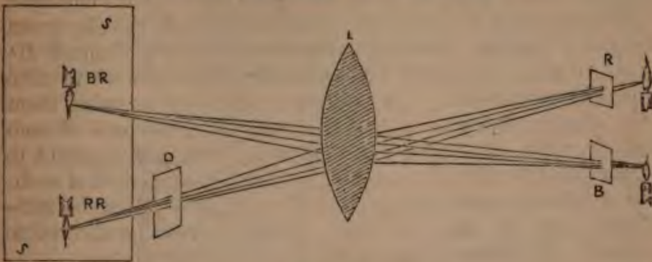


Fig. 215.

From experiments as to the power of distinguishing objects at a distance, it has been found that white objects on a black ground are more readily perceived than black objects on a white ground. This subject in time of war has engaged attention, in so far as it concerns the best colour for the clothes of soldiery, and it has been decided that the least visible is a light grey. Colonel Derinzy states, that on the day before the battle of Vittoria, a Portuguese rifle company dressed in earthy brown, and a company of British Fusiliers dressed in red, were equally exposed in an undertaking to dislodge the French from a bridge, and that after the skirmish the relative losses were as two of the British to one of the Portuguese. The danger arising from the colour of dress is in something of this ratio,—1st, red; 2nd, green; 3rd, brown; 4th, light grey.

The Rainbow.

That majestic and glorious sign in the heavens, the rainbow, is caused by the refraction and division of the rays of light into their prismatic colours, by means of drops of rain which act as so many prisms. Rainbows can only be seen decorating the vault of heaven when rain is falling opposite to the sun and the eye: the violet is the colour of the inner arch, which is encircled by indigo, blue, green, yellow, orange, and finally by red,—in fact, is a large solar spectrum in the form of part of a circle. The red rays make an angle with the rays of the sun of 42° 2′, the violet rays 40° 17′, and the other coloured

rays are between these; thus then the difference between 42° 2′ and 40° 7′ being 1° 45′, that must be the breadth of the rainbow. The inner or violet line forms part of a circle whose semidiameter is 41°, and its situation varies according to the height of the sun: the higher the sun, the lower the rainbow.

If *c d* (fig. 216) be two drops of water and *s s* rays of the sun incident upon each of them, those which enter near their centre will be refracted to a focus, as in a sphere of glass. But those which enter above or below will at once suffer dispersive refraction; and striking against the back of the drop, at a certain angle, they are reflected, and issue from the front. At the point of emergence they are refracted a second time, and suffer prismatic dispersion, when the red ray, as being the least refrangible, takes the lowest direction, and the violet, having the greatest refrangibility, takes the highest. If we suppose we have been speaking of the drop *c*, at a certain distance below it let *d* represent a similar drop. The same refraction and production of the prismatic colours will happen in this second drop *d* as in *c*, and at some point *f* the red ray of the upper drop will intersect the violet ray of the lower. Suppose a spectator to stand so that his eye shall be at *f*, then from the upper drop he will see red light, from the lower one violet, and from the intervening drops between these two extremes he will see the intermediate prismatic colours, and consequently between *c* and *d* he will see a perfect spectrum.

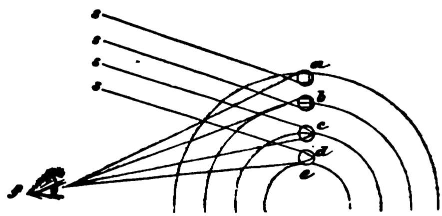


Fig. 216.

In *a* and *b* the rays *s s* enter the drops of rain at the lower part, where they receive their first refraction, at the lower part of the back of the drops their first reflexion, and at the upper part of the back their second reflexion, and lastly, their second refraction and inverted prismatic dispersion at the points of emergence from the drops; in this case the violet ray, as being that portion of light which is most strongly refracted, takes the lowest path, and the red ray, as being the

least so, takes the highest; this then is in inverse order to the drops *c d*. An eye, therefore, at *f* receiving the rays from *a* and *b* at their point of intersection, in the drop *a* will see the violet ray, and in *b* the red ray, and in the intervening rays between *a* and *b* the other prismatic colours, so that between *a* and *b* there will be a complete spectrum, whose lower extremity is red and the upper violet. This rainbow having a half diameter of 54°, it is sometimes observed without the other one, which only appears to a person on a plane when the sun is within 41° of the horizon. The rainbows above waterfalls, and the halos that sometimes surround the sun and the moon, are produced from the mist in the atmosphere, and are referred to the same principle as drops of rain creating the great and more intense rainbow which we have been describing.

A portion of a rainbow greater than a semicircle can only be seen when the observer is so situated as to have the sun below him; thus, for instance, if he be on a high mountain an arc becomes visible proportioned to his elevation; a complete circle of a rainbow may be seen in the spray of a cataract if the spectator be sufficiently elevated above the horizon. It will have struck the reader that each beholder sees a different rainbow, every drop of rain being viewed differently, or different drops only producing the beautiful vision according as the spectator may be situated.

The Eye.

The eye—that index of the soul, that channel of human knowledge—conjures up a host of feelings when the mind is directed to it as an object of special attention. The babe watches the rays of affection that beam from the maternal eye in sympathetic love and delight. The youth forms his ideas of those around him, and endeavours to divine truth in language, by watching the uncontrollable expression of the eye of those addressing the ear. The universal and irresistible feeling of reciprocal affection between the opposite sexes needs no other language than that expressed by the eye. Revenge and surprise, hatred and pity, joy and grief, all have distinctive and powerfully portrayed character in the eye. In infancy it is peered into as the symbol of the activity of the vital principle; in illness its look indicates the body's approach to

health or accumulation of disease; while in age the glazing over of the eye announces the close of all mortal feelings, and the flight of the soul to the judgment-seat of the divine Contriver of the beauties and wonders of the organization of man.

In its external appearance, what magnificence there is in the orb itself! sparkling as a diamond, the coloured parts varying in size with the amount of light; the exquisite little miniature of another being, or miles of variegated scenery pictured with a truthfulness belonging only to nature's pencil; a frame of bone protecting it from accidents; an arch of hair to ease a blow on the bone and turn the course of the "sweat of the brow;" then the eyelash catching the minute particles of dust, and the eyelids ever active in saving either from danger or injury the mirror underneath, and polishing and moistening the brilliant orb; while the motion of the adjoining parts is instigated by the emotions of the bosom, and gives outwards signs of the secret and hidden feelings within.

The eye is the perfection of optical instruments, no effort of art being able to form a lens to refract the rays of light with the excellence of that possessed by the eye.

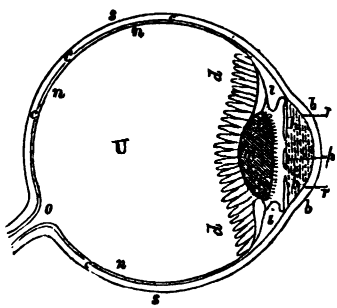


Fig. 217.

The globe-like object (fig. 217) is a representation of a section of the human eyeball a little above its usual size. Its mechanism is truly surprising, although simple; and it is formed in some essential particulars like the camera obscura. The strong covering *s s* is the part that appears white, and is named the sclerotica, or sclerotic coat, from its being a hard, tough, rigid and inelastic membrane of an interwoven fibrous texture. The window which admits the light is bowed out, *b b*, and called the cornea, from being, when dried, like fine horn, very transparent. In shape it is part of a segment of a smaller sphere than the eyeball itself. Nearly the whole of the eyeball is covered on its external surface by a highly vascular and delicate membrane

known as the conjunctiva; it is strong, flexible, and close in its texture. The outer part of the cornea is convex and the inner concave, rather thicker in the middle than elsewhere. It consists of two or more layers, which are separated by a limpid fluid. This fluid increases the density, and thus adds to the optical effects of the eye; it acts as a lens on the rays of light entering it. The second membrane *c c* is the choroid, so named from the resemblance of its outer surface to the chorion, a membranous investment of the egg. It is a thin soft dark brown structure, lining nearly the whole concave surface of the sclerotic, and terminates at *i i*. The purpose of this dark brown is to render the body of the eye a camera obscura or dark chamber. The colouring matter is called the pigmentum nigrum, from being of a dark colour in most animals. Just within the choroid is the central opening for the admission of light called the pupil *p*, and is bounded by a sharp well-defined circular edge; the pupil is surrounded by a coloured border of fibres called the iris *h h*, which acts as a curtain to admit more or less light on the pupil: when there is too much light the iris contracts, and when too little it dilates. It is the action of this part that is examined by medical men, as when not susceptible of the influence of light great danger is apprehended. It is the beautiful variety of colours here displayed that gives the character or name to eyes, and thus is derived its rainbow name of *iris*. The pupil, when expanded, will admit ten times the amount of light that it does when contracted. If we go from a light place into a moderately dark one, at first we cannot distinguish any thing; for the pupil being contracted, a sufficient quantity of rays of light cannot gain admittance, but as it dilates we gradually begin to perceive objects. If we go out of darkness into a glare of light the eye is pained; for the pupil being dilated, too much light rushes in before it is accommodated to the quantity. Behind the cornea is the aqueous humour *r r*, in which the iris and pupil are immersed; it resembles water, and is perfectly limpid, but holds in solution minute portions of several saline ingredients; behind this is the crystalline lens L *l*. It is formed like, and performs the offices of, a double-convex lens; but is not equal segments of spheres, the front being somewhat flatter than the back portion; it is the most refractive power in the eye. It is about the sixth of an inch

in thickness, and about twice that in length. The substance is arranged somewhat like the coats of an onion, being divided into three sections, the cleavage planes of which diverge from the axis of the lens at angles of 120 degrees. In composition it resembles the white of egg, and coagulates when boiled. The lens is enclosed in a transparent and highly elastic membrane, marked by a black line *m*, which shuts in a very small quantity of fluid for the purpose of preserving it in its true and useful shape. Its important function is to refract the rays of light, which it does in a manner that is perfection itself, and causes a most beautiful and perfect image of external objects to be formed on the back part of the eye. Should disease produce an opacity of the lens, it is called cataract; and the surgeon, after extracting it, substitutes a double-convex lens in the shape of spectacles, and sight is regained. The space behind the lens is filled with a humour *v*, which having a supposed resemblance to melted glass is called vitreous. It is transparent, of a jelly-like consistency, and preserves the spherical shape of the eye. This part is called the posterior chamber of the eye, and that portion before the lens the anterior. The substantial coverings of the eye are for the preservation of that most important part, *n n*, the retina; the optic nerve enters the eye at *o*, and spreads out in the form of a fine transparent membrane over the whole of the concave surface of the posterior chamber, thereby forming the retina; the outward portion of which resembles the matter composing the brain, and the inner part a most delicate web. It is on this that the images are thrown, and impressions received and conveyed to the brain.

The ciliary body *d d* is a thin, dark, annular band, like a frill of flat outspreading plaits, which encircle but do not reach to the circumference of the lens. The front is attached to the ciliary ligament, and to a small portion of the back of the iris. This has recently been proved to be a muscular body, exerting great influence over the movements of the iris. It is thickly coated and pervaded with pigment, except at the extremities of about seventy minute unattached points which fringe the inner margin, and radiate towards the lens like the florets of a marigold round its central disc; these are called the ciliary processes, and form a bordering around the window part of the eye.

We can see nothing but what is painted on the back of the retina of the eye; wonderful, then, must be the correctness and minuteness of the picture there impressed. But there is another fact which we have not yet noticed, which is, that every thing is there represented in an inverted position. The rays of light from the arrow *a r w* (fig. 218) fall on the cornea

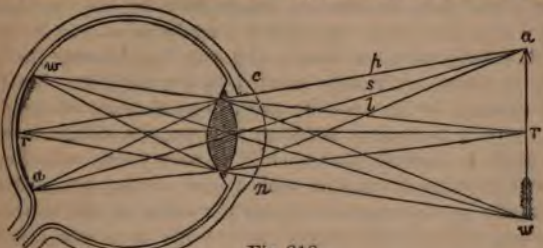


Fig. 218.

of the eye, between *c* and *n*, and passing through the pupil, lens, and humours, will converge to as many points on the retina, and there form a distinct inverted picture of the arrow *w r a*; because the pencil of rays *p s l* given off at *a* will converge to the point *a* on the retina, those from *r* to the point *r*, those from *w* to the point *w*, and the intermediate points in the same manner, by which means the perfect picture is formed, and the object becomes visible. Now, here is the curious point, that although on the retina the picture is inverted, yet we see objects erect. No satisfactory explanation has yet been given of this phenomenon; some writers appear to think that it is the sense of feeling, which from earliest infancy we practise, that corrects the sense of sight, and leads us always to judge things in a reverse position to that on the eye. On this point, and also on another singularity in respect to the wonders of vision, Dr. Arnott offers the following philosophic remarks: "It is known that a man with wry-neck judges as correctly of the position of the objects around him as any other person, never deeming them, for instance, inclined or crooked, because their images are inclined as regards the natural perpendicular of his retina; and that a bedridden person, obliged to keep the head upon the pillow, soon acquires the faculty of the person with wry-neck; and that boys who at play bend down to look backwards through their legs, although a little puzzled at first,

because the usual position of the images on the retina is reversed, soon see as well in that way as in any other. It appears, therefore, that while the mind studies the form, colour, &c. of external objects in their images projected on the retina, it judges of their position by the direction in which the light comes from them towards the eye, no more deeming an object to be placed low because its image may be low in the eye, than a man in a room into which a sunbeam enters by a hole in the window-shutter, deems the sun low because its image is on the floor. A candle carried past a keyhole throws its light through to the opposite wall, so as to cause the luminous spot there to move in a direction the opposite of that in which the candle is carried; but a child is very young who has not learned to judge at once in such a case of the true motion of the candle by the opposite apparent motion of the image. A boatman, who, being accustomed to his oar, can direct its point against any object with great certainty, has long ceased to reflect, that to move the point of the oar in some one direction, his hand must move in the contrary direction. Now, the seeing things upright, by images which are inverted, is a phenomenon akin to those which we have reviewed.

"Another question somewhat allied to the last is, why, as we have two eyes, and there is an image of any object placed before them formed in each, the object does not appear to us to be double? In answer to this, again, we need only to state the simple facts of the case. In the two eyes there are corresponding points, such that when a similar impression is made on both, the sensation or vision is single; but if the least disturbance of the position occur, the vision becomes double. And the eyes are so wonderfully associated, that from the earliest infancy they constantly move in perfect unison. By slightly pressing a finger on the ball of either eye, so as to prevent its following the motion of the other, there is immediately produced double vision; and tumours about the eye often have the same effect. Persons who squint have always double vision; but they acquire the power of attending to the sensation of one eye at a time. Animals which have the eyes placed on opposite sides of the head, so that the two can never be directed to the same point, must have in a more remarkable degree the faculty of thus attending to one eye at a time.

"The corresponding points in the two eyes are equidistant, and in similar directions from the centres of the retinæ, called the points of distinct vision, at which centres the imaginary lines named the axes of the eyes terminate; and it is worthy of remark that these points, in being both to the right or both to the left of the centres, must be one of them on the inside of the centre, as regards the nose, and the other on the outside. When the two eyes are directed to any object, their axes meet at it, and the centres of the two retinæ are opposite to it, and all the other points of the eyes have perfect mutual correspondence as regards that object, giving the sensation of single vision; but the images formed at the same time of an object nearer to or further from the eye than the first supposed, cannot fall on corresponding points; for an object nearer than where the axes meet would have its images on the outsides of the eyes, and an object more distant would have its images on the insides of the eyes, and in either case the vision would be double. Thus if a person hold the two forefingers in a line from his eyes, so that one may be more distant than the other, by then looking at the nearest, the more distant will appear double; and by looking at the more distant, the nearer will appear double.

"The reason of the term 'point of distinct vision,' applied to the centre of the retina, is discovered at once by looking at a printed page, and observing that only the one letter to which the axis of the eye is directed is distinctly seen; so that although the whole page be depicted on the retina at once, the eye, in reading, directs its centre successively to every part."

Dr. Alison is of opinion "that the harmony between the intimations acquired by sight and by touch, as the relative position of objects or their parts, notwithstanding that the impressions made by them on the external objects of sight and of touch are arranged inversely in regard to one another, arises from the course of the optic nerves and tractus optici, whereby impressions on the upper part of the retina are in fact impressions on the lower part of the optic lobes—that is to say, of the sensorium—and impressions on the outer part of the retina are, in like manner, on the inner part of the sensorium."

On this interesting subject many theories are advanced by those whose opinions deserve notice. Kepler considered that

objects appeared erect, from the mind perceiving the impulse of a ray on the lower part of the retina, and he conceives this ray to be directed from a higher part of the object, and *vice versá*.

Porterfield is of opinion that the mind never sees the picture painted on the retina, and therefore never thus judges of the object; and that in seeing any object, the mind, by virtue of a connate immutable law, traces back its own sensation from the sensorium to the retina, and from thence outwards, along right lines drawn perpendicularly from every point of the retina on which any impression is made by the rays forming the picture towards the object itself, by which means the mind always sees every point of the object, not in the sensorium or retina, but without the eye, in these perpendicular lines. But these lines nearly coincide with the axes of the several pencils of rays that flow to the eye from the several points of the object; and since the mind has also the power of judging rightly of the distance of objects, it follows that every point of the object must appear and be seen in the place where it is; and consequently that the object must appear in its true erect position, notwithstanding its picture on the retina is inverted.

Reid and Brewster incline to the above opinion; but Müller objects to the hypothesis that erect vision is the result of our perceiving, not the image on the retina, but the direction of the rays of light which produce it; involving an impossibility, since each point of the image is not formed by rays having one determinate direction, but by an entire cone of rays. And, moreover, vision can consist only in the perception of the state of the retina itself, and not of any thing lying in front of it in the external world. The hypothesis also that the retina has an *outward* action, and that objects are seen in the direction of decussating lines, that is to say, in the direction of the perpendicular of each point of the concavity of the retina, is a perfectly arbitrary assumption; since there is no apparent reason why one direction should have the preference rather than another; and each ultimate sensitive division of the retina, if it had the power of action beyond itself, would act in so many directions as radii might be drawn from it towards the exterior world.

It appearing, then, that there cannot be perfect sight unless

where a perfect image is formed on the retina, and the truth having been formerly explained, that images behind any lens will be at different distances from it, according to the various distances of the objects in front, that is to say, according as the pencils of light which fall upon it have more or less of divergence in them, it follows that the eye, in being able to see distinctly objects at any distance beyond five inches, possesses a power of altering the relation of its parts to accommodate itself to the circumstances. This change is effected by a set of muscles which produce some alteration in the form of the lens and eyeball: but among the human race it happens that all do not originally possess these powers exactly in the requisite degree, and that many lose them, as life advances, from a natural decay.

The imperfection called short-sightedness is perceptible in the prominency of the cornea, and arises from the too great convexity of the cornea or lens. Thus in fig. 219 it will be

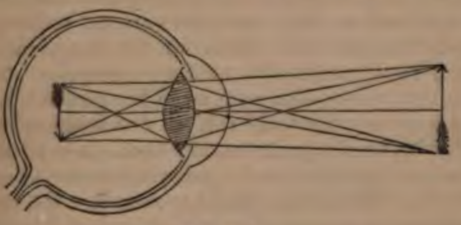


Fig. 219.

seen the rays are too much refracted, and brought to a focus before arriving at the retina, consequently the rays again spread, and the object is rendered indistinct. Persons so afflicted hold anything they have to look at near to the eye, by which the rays falling on the crystalline humour are more divergent and do not so soon come to a focus. To lessen the defect, which is a serious inconvenience in crowded streets, concave lenses are fitted into frames, and then called spectacles; these are placed before the eye, and cause the perfect image to be formed further from the lens in the eye, and hence not brought to a focus until it reaches the retina. The nearer an object is brought to a lens, the further the image recedes.

Short-sighted people require concave lenses, as in fig. 220,

where the rays of light proceeding from *a* pass through the lens *e e*, and are brought to a focus on the retina at *f*, as shown by the dotted lines: whereas without the intervention of the lens *e e*, the rays would be brought to a focus at *d*.

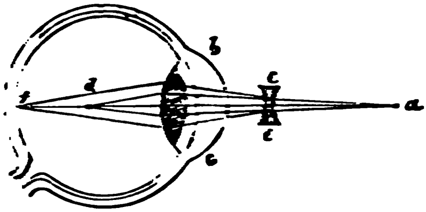


Fig. 220.

Myopism, as it is generally called, is increased by using glasses more powerful than necessary. The eyes of such persons are mostly strong, that is, capable of great exercise in reading, writing, drawing, and other works dependent most particularly on eyesight, and in which the lenses are not requisite; this in some respect recompenses them for the disagreeableness and disfigurement of perpetually wearing spectacles. This defect generally diminishes with years; and the person who in youth needed spectacles, in old age can see well without them.

Long sight, presbyopy, is exactly the reverse of short sight, and in many instances equally annoying from not seeing near objects well. Thus in fig. 221, it is seen that the rays of light do not collect to a focus on the retina at *a b*, but do so at *c* behind

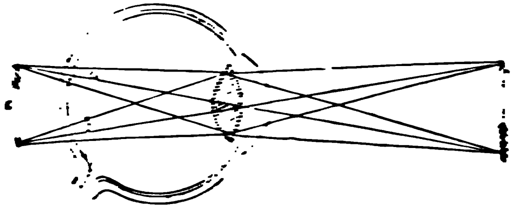


Fig. 221.

it, and hence long-sighted persons hold an object at a distance from their eyes; for the more distant the object is from the crystalline lens, the nearer the image will be to it, and thus be brought to the proper position on the retina, whereby such

persons can see distinctly. The auxiliaries of science to the long-sighted are convex lenses *e e* (fig. 222) fitted up as spectacles, which causing the rays of light proceeding from *a* to converge, are brought to a focus on the back of the retina at *f*,

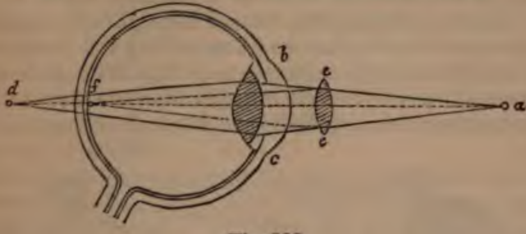


Fig. 222.

instead of passing as it were beyond it to *d*: the dotted lines show the effect of the convex lens *e e*.

These are not the only cases of defective vision; others arising from malconformation of the cornea are much more common than has been supposed, and it is said that few eyes are free from them. One eye may be alone affected; and a most remarkable and instructive instance of this defect has been adduced in the person of the Astronomer Royal, Professor Airy. In his case it arose from a defect in the figures of the cornea and lens: he ascertained the eye to refract the rays to a nearer focus in a vertical than in a horizontal plane, which rendered the eye utterly useless to him, and a serious impediment to his astronomical investigations. To correct this, after much thought, Professor Airy himself contrived to have made a double-concave lens, in which one surface was spherical, and the other cylindrical. The use of the spherical surface was for the purpose of correcting the general defect of the too-convex cornea. And in his own words: "After some ineffectual applications to different workmen, I at last procured a lens to these dimensions: radius of the spherical surface $3\frac{1}{8}$ inches, of the cylindrical $4\frac{1}{2}$, from Mr. Fuller, of Ipswich. I can now read the smallest print at a considerable distance with the left—the defective—eye as well as the right. I have found that vision is most distinct when the cylindrical surface is turned from the eye; and as, when the lens is distant from the eye, it alters the apparent figure of objects by refracting

differently the rays in different planes, I judged it proper to have the frame of my spectacles made so as to bring the glass pretty close to the eye. With these precautions I find that the eye, which I once feared would become quite useless, can be used in almost every respect as well as the other."

An ingenious instrument, termed the Ophthalmoscope, has been invented for the purpose of examining the changes produced by disease in the internal eye. Fig. 223 represents the instrument in use. The rays from the flame of a lamp, reflected by a concave mirror A B, fall in a state of convergence on a

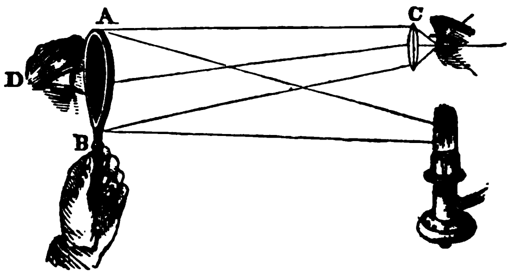


Fig. 223.

convex lens C of about 1½ inch focus, held just before the eye under examination. The rays of light are so much converged by the additional refraction they undergo on entering the eye, that they quickly come to a focus, cross, and are dispersed over the retina, and thus this membrane is fully illuminated. The observer's eye at D is looking through the small central aperture in the middle of the concave mirror, which he holds in his hand.

The earliest observation, and which doubtless led to the discovery of the ophthalmoscope, was the mirror-like reflexion of light seen to emanate from the eyes of certain animals. Prevost demonstrated, in 1810, that this was produced by a ray of light falling upon the eye, and, being reflected back, gave the eye that mirror-like appearance, to see which perfectly, the animal must be in a darkened place, and the light made to fall upon it from without. This observation has only lately been revived and studied by Cumming, Beer, Erlach, Helmholtz, Brücke, and others, in the human eye. [The

instrument and its uses are fully described in a little work by Mr. Jabez Hogg.]

The focal centre of the eye is generally admitted to be at a very little distance behind the crystalline lens, and the angle formed by the intersecting axial rays from the two eyes is called the *visual angle*. In looking steadily at an object with both eyes, it has to be brought into the focal centre of the produced visual axis, and in doing this the eye revolves round a point which is the *focal centre*. The motion is accomplished by the reciprocal sympathy of the muscles of each eye mutually acting together.

The eye, on seeing a landscape, does not take in all the points at the same time; but so rapidly does it move, that by the retention of points on the retina, the picture seems a whole, and the mind receives it as if all was seen at the same instant. Hence it is believed that we only see perfectly the particular points of an object when the axis of the eye is in a direct line with it. Dr. Young states, that by fixing the eye steadily in its usual position, a little forward and downward, and moving a luminous object, the range of vision upwards is 50°, downwards 70°, inwards 60°, and outwards 90°; that is, a horizontal play of 150°, and a vertical play of 120°. But of course different eyes vary in their powers.

If a person look down upon a human eye immersed in water, as may be tried when bathing, the iris will be seen shining brightly inside the eye, while the cornea will seem to have disappeared, and water penetrated the eye. The illusion is so perfect as to alarm the person who gazes on an eye so situated, from its unnatural appearance. The diver, when he looks upwards, sees things as if through a small round hole; but all objects are visible, those near the horizon distorted, and contracted as to height.

If we gaze at the bright sun, and then close our eyes, various colours are seen before the form of the object disappears. Sir Isaac Newton experimented on this subject, and wrote an account of it to Locke. He describes first looking at the sun, and then seeing the visionary appearance afterwards. "At length," says he, "by repeating this, without looking any more at the sun, I made such an impression on my eye, that if I looked upon the clouds, or book, or any bright object, I saw before it a round bright spot like the sun;

and, what is still stranger, though I looked upon the sun with my right eye only, and not with my left, yet my fancy began to make an impression upon my left eye as well as upon my right; for if I shut my right eye, and looked upon a book or a cloud with my left eye, I could see the spectrum of the sun almost as plain as with my right eye, if I did but intend my fancy a little while upon it; for at first, if I shut my right eye, and looked with my left, the spectrum of the sun did not appear till I intended my fancy upon it; but by repeating this it appeared every time more easily. And now, in a few hours' time I had brought my eyes to such a pass, that I could look on no bright object with either eye, but I saw the sun before me, so that I durst neither write nor read; but to recover the use of my eyes, shut myself up in my chamber made dark for three days together, and used all means to direct my imagination from the sun; for if I thought upon him, I presently saw his picture, though I was in the dark; but by keeping in the dark, and employing my mind upon other things, I began in three or four days to have some use of my eyes again, and by forbearing to look upon bright objects, recovered them pretty well, though not so well but that, for some months after, the spectrum of the sun began to return as often as I began to meditate on the phenomena, even though I lay in bed at midnight with my curtains drawn."

What amazing adaptation has the eye to circumstances affecting it, when we have the power of reading by the light of the full moon and the noonday sun, the difference of their intensities being as one to three hundred thousand!

Our perception of objects arises from the impressions on the retina being communicated by the optic nerve to the brain, where they are what we call recognized by the mind; thus, we do not see the objects painted on the retina, as we would need another eye to do so. When the nerve is diseased or injured, the retina may receive the image, but the mind no longer is susceptible of the impression. When the brain is disordered the optic nerve sympathizes so much, that, without the retina having such an object upon it, there is presented to the mind those singular delusions cleverly described in the 'Philosophy of Apparitions;' while in fever, and the gradual decay of the healthy state of the nerves on the bed of death, there arise many remarkable delusions.

An optical spectrum is seen when the eye has been strained by looking on any particular object or colour. The ray of white light consists, as we have shown, of three primitive colours. Now, if the eye is fatigued by one of these colours, or it be lost, mechanically or physiologically, the impression of two only will remain, and this accidental or complementary colour is composed of the two remaining constituents of the white ray. Thus if the eye has been strained on a *red* colour, it is insensible to this, but perceives the *blue* and the *yellow*, the combination of which is *green*. So, if we look long on a *green* spot, and then fix the eye on *white* paper, the spectrum will be of a light *red*. A *violet* spot will become *yellow*; a *blue* spot *orange-red*; a *black* spot will entirely disappear on a *white* ground, for it has no complementary colour; but it appears *white* on a *dark* ground, as a white spot will change to black. The colours of objects are also changed in some cases of ophthalmia: the eye, from certain diseases of the nerve, may only see half its objects; the same things may appear and disappear alternately; objects at rest may appear in motion; and the spectral images of persons and things formerly seen may be exactly reproduced. Even more than this may occur physically, for material objects may seem what they are not, and especially under certain predisposing causes of a mental nature.

Optical illusions, at times, present themselves in very curious and mystic aspects; which is doubtless owing as much to some temporary derangement of the organ of vision, as to that of bodily ill health, or to external refraction.

One of the sublime provisions with which the eye is gifted is the duration of the impressions on the retina, so that we are enabled in the frequent flashing of the eyelids over the eye never to lose sight of the object engaging our attention.

There are several conditions necessary to convey the impression of the object to the optic nerve, and from thence to the brain. Of these one is a certain length of time for light to excite the impression, which, after doing so, is retained after the cause has ceased. M. D'Arcy found that when a live coal was swung round in a circle 165 feet distance, the impression remained on the retina a little above the seventh part of a second. But the duration of the impression depends on the colour of the light, for white remains longest, next yellow, then red, and blue the shortest period. Taking the average

length of time for the duration of the impression by all the colours, from the instant of their maximum intensity till their disappearance, it is found to be one-third of a second in a dark room, and one-sixth of a second in a light room. If two or more impressions succeed each other at such short intervals so that the first has not faded away before the next commences, they run into each other, the eye seeming to receive them as if they were but one impression, as we know when we whirl round a piece of burning stick, which seems like a perfect circle of fire. Fireworks produce this effect, and lightning appears as a stream of light. The retina must also be exposed to the influence of an object before it can be visible: thus the flight of a musket-ball being too rapid to cause an impression, it is not seen: again, if the luminous impression be too weak, the object cannot be discerned. Innumerable optical toys and pyrotechnic apparatus owe their effects to the continuance of the impression on the retina, when the object has changed its position. The *thaumatropes*, *phenakistiscopes*, *phantascopes*, *anorthoscopes*, Gorham's colour-top, &c., are all explained upon this last-mentioned principle.

In using a lens, those rays that fall upon it at a distance from the axis, intersect those that fall upon it nearer to the axis, and consequently, on being refracted nearer the lens than the principal focus, indistinctness is created, an effect which is called spherical aberration: this in lenses is remedied by covering the rims, or part of their surfaces, by some substance which is not transparent, so that the rays pass through only that part where, on meeting after refraction, they will be at one point. In the eye this indistinctness is provided against by the shape of the crystalline humour, the place of the iris, which also covers up a portion of the lens, and by the concavity of the retina, all combining most wonderfully to effect the desired object, and perfection of vision.

We know that in an artificial convex lens it is limited in its power, according to distance, of showing distinct images, yet, resembling it as it does, the human eye has a beautiful muscular adaptation by which distant as well as near objects may be instantaneously seen in a most distinct manner: a power of self-adjustment, although limited, yet most important to our happiness and preservation of life.

Even achromatic object-glasses are so far imperfect, that they

do not bring the *chemical* rays of light to the same focus as the *luminous* rays. There is likewise another property termed *latent* light, or the influence and principle of light in darkness. The continuating rays of light are those that would appear to prolong the disturbance of the surface of a body once set up or begun. The yellow are the continuating rays: by means of these, photographers are enabled to develope an invisible image when the change has been once begun or set up on the chemically prepared surface.

This curious property of the yellow rays of light may afford us some clue to the use of the yellow spot in the central region of the retina, known as the yellow spot of Sœmmering, not far removed from the optic nerve itself, but where the light as it enters the eye is first received: we may therefore suppose the retention of the impressions to be stronger here, owing to the continuating power of this yellow spot. It is quite certain that the retina at this very spot is more sensitive than elsewhere, which no doubt arises from the luminous rays acting more energetically upon it.

Here we have a curious and important physiological inquiry, affording some explanation of the indelible fixed impress received with the rapidity of an electric flash, and hence conveyed to the mind, to be there reproduced at will with the same vividness years after the first momentary impression was received upon the retina.

There is another remarkable fact which must not escape our attention: at the spot where the optic nerve enters the eye it is totally insensible to the stimulus of light; for this reason it is called the *blind spot*. It is known that at this point the nerve is not yet divided into those almost infinitely minute fibres, which are fine enough to be either thrown into tremors or otherwise changed in their mechanical, chemical, or other state, by a stimulus so delicate as the rays of light. A simple and curious experiment will at once prove its existence. On a sheet of black paper, or other dark ground, place two white wafers, having their centres three inches distant. Vertically above that to the *left* hold the *right* eye at twelve inches from it, and so that, when looking down on it, the line joining the two eyes shall be parallel to that joining the centre of the wafers. In this situation, closing the left eye, and looking full with the right at the wafer perpendicularly below it, this only

is seen, the other being completely invisible. But if removed ever so little from its place, either to the right or left, above or below, it becomes immediately visible, and starts as it were into existence. It will cease to be thought singular, that this fact of the absolute invisibility of objects in a certain point of the field of view of each eye, should be one of which scarcely one person in a thousand is apprised, since it is well known to medical men that persons have been totally blind with one eye without their being at all aware of the fact.

We judge the dimensions of objects, that is, their real from their apparent magnitude, by the angle under which its rays intersect each other in the eye, aided by its distance, position, and motions, which our judgment draws conclusions from by continued exercise, commencing in earliest infancy, assisted by experience in after life. We infer the size of distant objects from the decrease of the visual angle, as well as the relative distances of objects from each other by the angle of vision varying at each point. The apparent or linear magnitude must be of a certain size to produce an image on the retina, besides an illuminating power and colour. The image of an object moderately illuminated must be 0·001 of an inch long, or the extreme rays of light must form an angle of half a minute in the eye at a minimum; whence it follows that an object of mean illuminating power will be visible if its distance from us is not more than 68,000 or 69,000 times its greatest length. Strongly luminous bodies, such as the fixed stars, are visible at infinitely small visual angles; they excite in the eye merely a sensation of light, without creating any impression as to their apparent magnitude or even form.

Plateau asserts that white may be distinctly seen in the light of the sun at an angle of 12″, yellow at one of 13″, red at 23″, and blue at 26″; but that in ordinary daylight these angles must be half as large again.

We judge of the motions of bodies by their images moving on the retina; but to be able to detect motion, the line of vision must describe at the least one degree in each minute of time: this not being the case with the heavenly bodies, their motions are imperceptible. The nearer the direction of the motion is at right angles to the line of vision, the greater will be the apparent motion produced by any real movement of an object. The hour-hand on a clock stealing stealthily along

is not perceptible, from having less motion than that stated above.

At the first glance at the subject of single vision, it seems strange with two eyes, having each an impression of an object on the retina, that we do not see the object double. But the beautiful mechanism of the muscles that move the eyes acts in such perfect unison, that the axes of the eyes converge towards the object to which they are adjusted, and the image falls exactly on the same parts of the two retinæ.

If $a\,b$ (fig. 224) be the two eyes, and c the object before them, $a\,c$, $b\,c$ are the axes that meet in c, therefore an image is produced in each eye which will correspond with the perspective projection of the object from the points a and b. But if the eyes be set so that their axes meet either before or beyond the object, then we see the object double. Thus, if a candle be at a distance of about ten feet, we see it distinctly as one object;

Fig. 224.

but if we place a finger, F, fig. 225, at about ten inches from the eyes, and look steadily at it, then a candle, D D, will be seen on both sides of the finger. This arises from the axes of the eyes meeting at the finger, and their crossing one another; the rays from the light passing on each side of the finger produce two images of the candle on the retinæ. But if the optic axes be directed to the light C, then the finger will be seen double, E E, on each side of the light.

Should, however, the object be brought so close to the eyes that the optic axes converge, then the perspective projections of the object are seen differently by each eye, and increase in difference the nearer the object is brought towards the eyes, from the greater convergence of the optic axes. Thus, when we place an object within two or three inches of the eyes, and look at it first with one eye and then with another, the head being kept in the same position, the perspective projections will seem to be different; we thus compel the eyes to converge to the degree of squinting, whilst with distant objects they are nearly parallel. The quality of focal change becomes of more value and importance in cases where the sight of one eye is lost. A person suddenly deprived of the use of one eye esti-

mates with the greatest difficulty the distance of objects. It would be almost impossible to snuff a candle with one eye closed, or even to place the finger exactly on any fixed point. The single eye, like the single leg of a compass, cannot at first measure distance; but, after some time, experience teaches the one eye to estimate distance by the change of focus alone, whilst with both eyes we feel and measure distance by the convergence and divergence of the visual axis.

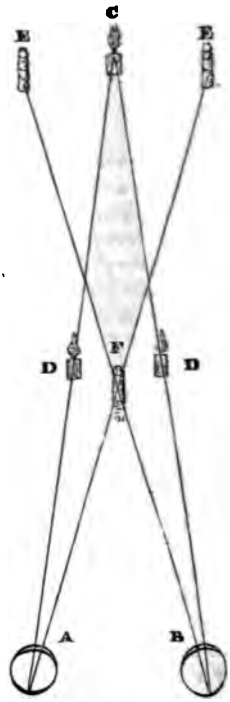


Fig. 225.

The Stereoscope.

The remarkable phenomenon just alluded to, engaged the attention of Professor Wheatstone, who, on the 21st of June, 1838, read a paper at the Royal Society "On some previously unobserved Phenomena of Binocular Vision" (sight with two eyes); in the course of which he described an instrument, the *Stereoscope*, invented by himself, by which two perspective diagrams of the same solid were seen at one view, so as to appear as completely solid as the object itself.

In 1839, Mr. Wheatstone brought his discovery before the British Association, at Newcastle, where it gave rise to a discussion of great interest, in which Sir D. Brewster and Professor Whewell took part; and Sir John Herschel characterized the discovery "as one of the most curious and beautiful for its simplicity in the entire range of experimental optics." In Germany the subject excited still more interest, and was at once eagerly taken up. The new light thrown on the subject of double vision engaged the attention of the most able physiologists and metaphysicians; and M. Prevost contributed an able and scientific paper on the subject. In the commencement of 1839, the photographic art, upon which Niepce, Talbot,

and Daguerre had long been at work, was at length matured; and Mr. Talbot and Mr. Collen in the same year, at Mr. Wheatstone's request, prepared photographs of full-sized statues, buildings, and portraits, for the stereoscope. Mr. Wheatstone's diagrams were at once a proof that small drawings may be made to represent under the stereoscope the complete effect of reality. Two miniatures might be painted, each with one eye, if the artist could attain sufficient accuracy, which, viewed in the stereoscope, would be seen as one solid, life-like picture.

These, however, were not the only illustrations of an important discovery in science. A new step was gained in explanation of a certain phenomenon of sight. It was clear that the inner eye (if we may use the phrase) is furnished with two outer eyes, not merely for the uniformity of the face, nor to puzzle philosophers, but to provide for an instantaneous perfect vision of the form and position of objects; the one eye, in fact, seeing round one side, the other eye round the other side, and the inner eye having thus brought before it in one and in full solidity the whole object.

That the same body is seen differently by the two eyes, will be rendered more intelligible by considering the relative position of the rays proceeding from the several points of the pyramid (fig. 226) to the eye. Let the pyramid *a*, placed on the table *b*, be viewed by the eyes of a person looking perpendicularly down upon it, and suppose that lines drawn from the several corners of the pyramid to each eye be intercepted by a screen *c*, placed parallel to *b*; of these the four back lines only are drawn in the diagram. By joining the several points where these lines pass through the screen, we obtain the figures drawn on it, which are the *projections* of the pyramid, and which correspond with the images produced on the two retinæ. It will be seen from the relative position of the lines drawn from the two eyes to the pyramid, that the projections on *c* will be necessarily dissimilar, the interior squares being nearer to the contiguous sides of the outer ones; and it is from the supposition of these dissimilar images that the mind infers the elevation of the smaller square above, or in front of, the larger one, and consequently the true relative position of the lines drawn one to the other, forming the lateral edges of the pyramid.

The word stereoscope is derived from two Greek words, signifying *solid* and *to see*. It therefore applies to an instru-

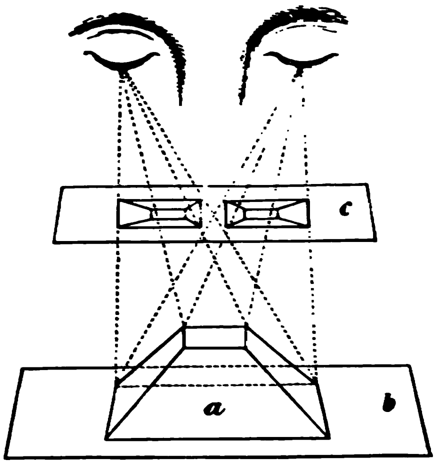


Fig. 226.

ment which enables us to view two plane surfaces in such a manner that they appear as a natural figure in relief. One figure in the stereoscope should represent a solid body exactly as viewed with one eye; the other, as viewed with the other. They should differ just as much as any near object is seen to differ from itself, on alternately shutting either eye. Thus in taking photographic views for the stereoscope, the camera should be shifted only a few inches (in fact, the distance between the eyes) for the second operation. It is very common for the pictures to be taken from points of view at a greater distance apart—several feet instead of inches. The result of this is, that, on viewing both simultaneously, a *model* is seen, not a natural object. An unnatural relief is obtained as if we can see too far round the corner, or regard three sides of an object at one moment.

The theory of the stereoscope is extremely simple. In this instrument two flat pictures—representing the same object as regarded from two separate points at a small distance apart—are so arranged as that one shall be seen by each eye. The

two come, as it were, to a focus in the brain, and give the idea of a solid body. Two eyes must of course be used in regarding them; when we shut one eye in looking about us, we see everything as a flat surface; when we open both, we see as it were two sides of each object, and thus at once know it to be in relief, or solid. The difference between the stereoscope and nature is, that in the former the two impressions do not come from the same point; and as the viewing two distinct objects with the two eyes would necessitate squinting to some extent, the ordinary refracting stereoscope causes the image to *seem to come from the same point,* and so allows of the natural convergence of the axes of the eyes.

The form of the stereoscope, as originally produced by Professor Wheatstone, and which he called the reflecting stereoscope, is shown in fig. 227; and it is on many accounts the

Fig. 227.—Reflecting Stereoscope.

most convenient form, as it allows of every adjustment, and will show pictures of any size. A reflecting stereoscope may be readily constructed. It consists of two pieces of looking glass set at right angles to each other in the centre part of the instrument. The objects or designs are slid into grooves at each end of the instrument, which are then some four or five inches distance from the reflecting mirrors, care being taken to place each design in its proper position. For small photographs, the refracting or prismatic stereoscope (fig. 228, also constructed by Mr. Wheatstone) is better adapted. Several ingenious modifications of the instrument have been made by Professor Dove and Sir David Brewster. The lenticular instrument described by the latter, which is most generally in use, has the

sppearance of a double opera-glass; and the chief modification consists in the substitution of quarter lenses for the prisms employed by Mr. Wheatstone. The eye-glasses refract, or, in other words, throw the images out of the direct line to the centre between the eyes; each image being in this way removed in a direction towards each other, the two combine, and produce the effect of solidity.

Fig. 228.—Refracting Stereoscope.

The diagrams of several forms of crystals and geometric solids are illustrations which may be observed without any instrument, to the no small amusement of those who for the first time see them, and may be multiplied in almost infinite variety. These diagrams are constructed to represent what may be termed right and left eye views of objects, as we should actually see them with the left or right eye alternately. Take, for example, the railway tunnels (fig. 229), and squint at them so as to view one with each eye: one picture will present itself, a central one, being a combination of the other two, and producing the effect of a perfectly hollow tunnel; in like manner the other diagrams will combine to form an apparently perfect solid body, presenting all the appearance of a network standing out from the paper. The idea of solidity is

evidently produced by the combination of two pictures of a solid body taken from either eye, as from two different points of sight. The perception of distance or perspective Mr. Wheatstone attributes to the same cause; which explains the

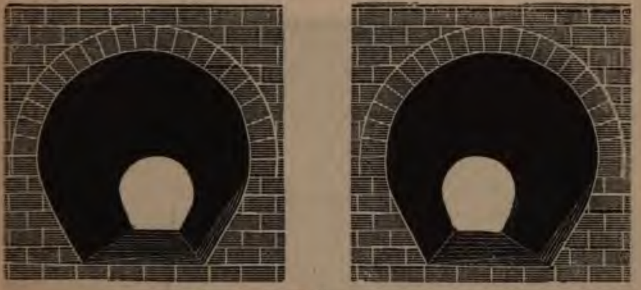


Fig. 229.—Railway Tunnel.

fact that all paintings and drawings are, in reality, but pictures for one eye, and are seen most like reality when they are looked at with one eye only. We may have distance, dimness, difference of light and shade, but cannot have real roundness and space between and beyond objects, unless each eye has its picture. As it is, our paintings may be said to be a one-sided or one-eyed perspective—the whole landscape or portrait as it would appear to the two eyes cannot be represented.

Fig. 230.—Iron Trellis-work.

So long as mere drawings by hand were used, it might be

held that the effect, however wonderful, was but some trick of art by which the senses were cheated. Photography, however, admits of no trick; the two plates in the two cameras stand truly for the two eyes, and receive each just such a picture, no more, no less, as each eye receives. There is, therefore, no

Fig. 231.—Double tetrahedron, the sides being equilateral triangles.

further room for doubt as to the need for two eyes; we have taken by the aid of photography the very picture from each, and have made them tell their secret. Our double vision is but perfect vision.

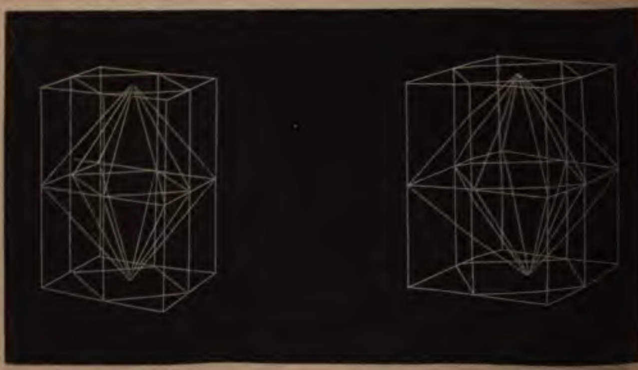


Fig. 232.—Square prisms, and octohedrons with square bases—the forms of the crystals of ferrocyanide of potassium, bicyanide of mercury, idocrase, and anatase.

It will be said that persons with one eye nevertheless see distinctly, and see perspective and rotundity. They do so; and there is neither difficulty in the answer, nor any refutation in the fact of what we have said as to double vision. One eye alone judges of the relief of an object, from the accustomed distributions of light and shade, giving perspective appearances, though the perceptions it hence acquires are less vivid than those obtained by means of two eyes. Another curious fact is, that a one-eyed person when looking at a solid object is constantly changing the position of the head from side to side: the result of this is, that he is by this means getting the same effect with one eye that is produced by two

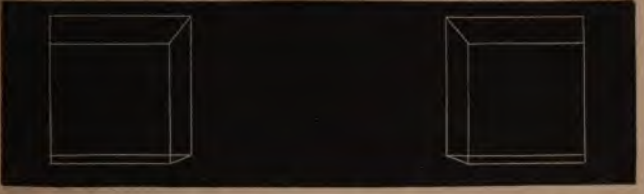


Fig. 233.—The regular tetrahedron—the form of crystals of copper, nickel, gold, alum, common salt, arsenious acid, fluor spar, and iron pyrites.

eyes with the head stationary. With two eyes, as we have before stated, two images from different points of sight are

Fig. 234.—The natural crystal of the topaz with cleavage at right angles to its three axes.

combined to produce solidity; with one eye, and a constant change of its position, two images in like manner are produced; but the combination depends on the curious circumstance of the second impression falling on the retina before the previous impression has escaped. The retention of objects on the retina some time after their removal has been before explained: therefore a one-eyed person, with the stereoscope, by first looking through one side and then through the other, gets the effect of distance and solidity simply by the retention of the first picture on the retina.

The complete perspective of distant portions of the picture in the stereoscope is not seen to perfection until it has been looked at for some seconds, though the near portions stand out in their full roundness and solidity at once. This arises from the instrument not being perfectly adjusted to the eyes of the observer, whilst it requires for instantaneous perfect vision a different adjustment for different persons. By attentive observation it may also be noted that the near and distant objects do not clearly appear at the same instant. This arises from the fact, that whilst the near objects are seen by each eye at a certain angle, and so that the two pictures form one, the distant objects, with eyes placed at the same angle, are more or less separated, and so are seen more or less distinctly as two pictures. To correct this, the eyes alter their distance from each other, and it is only when they have done so with accuracy, that the distant portions of the picture are made to coincide, and the roundness of the furthest portions is seen as distinctly as that of the nearest. This process of adjustment of their two pictures, both as to real objects and their photographs, the eyes are incessantly at work upon.

These stereoscopic pictures are not only curious, they are beautiful and useful. We have now galleries of portraits which are no fictions of painters, but people as they were and are—not flat and framed, and hung along the walls, nor in cold marble, but round and real as the originals look in life. And so with buildings and scenery; we have, at a cheap rate, our hall of antiquities—Pompeii as it is, Nineveh as Layard saw it—scenery in foreign lands, in our own, in all the minuteness, grandeur, and beauty of nature. Neither Claude nor Turner could have given more than half such physical or aërial perspective. The artist may carry in his stereoscope the

immortal works of the genius-inspiring masters of every age and country; and wherever the highest living beauty is to be found, he may have in an instant his models, subject to no errors of his pencil, but in all the full roundness of reality.

Another wonder of binocular or two-eyed vision is Professor Wheatstone's pseudoscope, an instrument so called on account of its giving false perceptions of all external objects. Some of the illusions are very extraordinary. Its effect may be briefly expressed as making whatever point is nearest seem furthest off, and the reverse; so that all objects seen through it appear as if they were turned inside out. A solid terrestrial globe is seen concave, like Wyld's globe, with the map on the inside. The inside of a tea-cup appears a rounded projecting solid. A China vase, with embossed coloured flowers, appears as if it were cut in two; the side with the flowers being indented. A bust shows as a deep hollow mask. Other more complicated, and in some cases perplexing, illusions are produced by the instrument, which is very portable, and will, from the infinity of its illusions, even as a toy, become popular.

The Telescope.

By the invention of the telescope man may almost be said to have created another sense, for with it he has rent asunder the veil bounding his knowledge of the universe, and peered into space hitherto hidden from his ken. By the telescope he has gained insight into the undeviating laws of creation. The telescope has taught humility to man—has shown that his mind cannot grasp the extent and wonders of the works of God—and that his duty is to adore that Power which is beyond his understanding.

The word 'telescope' is derived from the Greek, and means to see afar off.

The telescope is said to have been discovered by some children when at play in a Dutch spectacle-maker's shop; others state that Zacharias Jansen, a spectacle-maker of Magdeburg, trying the effects of a convex and concave glass united, found, that when placed at a certain distance from each other, they had the property of making distant objects appear near to the eye. However this may be, the first application of it to the purposes of science was by the celebrated Galileo.

The telescope consists of a long tube painted black in the inside to absorb superabundant light, and containing certain lenses. That which bears the name of Galileo's telescope, consists of a convex object-glass D S (fig. 235), and a concave eye-glass *c y*. The distance between the two lenses is less than the focal distance of the object-glass, but the concave glass is situated so as to make the rays of each pencil fall parallel upon the eye, as is evident by conceiving the rays to go back again through the eye-glass towards its focus. When the sphere of concavity in the eye-glass of a Galilean telescope is

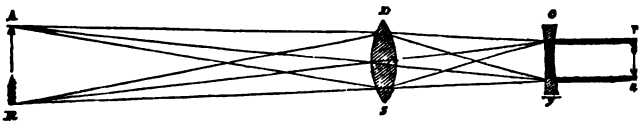


Fig. 235.

equal to the sphere of convexity in the eye-glass of another telescope, their magnifying power is the same; but the concave glass being placed between the object-glass and its focus, the Galilean telescope will be shorter than the other by twice the focal length of the eye-glass. Hence, if the lengths of the telescopes be the same, the Galilean will have the greatest magnifying power. It will be seen that the eye-glass receives the convergent rays before they meet and form the image, and by refracting them makes the rays diverge, and the object is seen at *r a*.

A cheap and really useful telescope may be made by obtaining a single convex lens of four, five, or six feet focus, which lens can be had of an optician for half-a-crown. The tube may be made of paper, of the required length, to suit the focus of the object-glass. Make also two more tubes of tin for an eye-piece, one to slide within the other, the larger one to slide in the tube of the telescope. The annexed diagram will explain what we mean:—D (fig. 236) is the body; A is

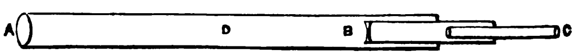


Fig. 236.

the object-glass; B C is the eye-piece. This is somewhat like

the Galilean telescope just described, but with this material difference, a compound eye-piece is used in this, whilst in the Galilean only a single eye-glass is used. B is a concave lens, and C is plano-convex, each of four inches focus. By placing B before C, it doubles the power of the eye-piece, and gets rid almost entirely of the prismatic colours, whilst its definition approaches that of an achromatic. This eye-piece can be used as a pancratic. If you pull C out, you must push B nearer to the object-glass. But two or three trials will be required to adjust the glasses of this telescope, which will show the satellites of Jupiter, and also the dark belt across the body of the planet.

The Galilean is an extremely simple instrument, and from its portability is used as a pocket telescope; when constructed on a small scale it is called an opera-glass. It possesses but a limited field from the dispersion of the light by the concave eye-glass, and has not a great magnifying power; yet it affords a distinct and clear view of objects, enlarging their proportions, and is used in observing objects on the surface of the earth.

To obtain a greater magnifying power and a just proportion of the objects, "aërial" telescopes, frequently more than 100 feet long, were at one time used. The object-lens was fixed on a pole in a frame, and moved by means of a string or wire; no tube was used excepting one to hold the object-glass, with proper arrangements for its movement.

The size of an object-glass does not add to the magnifying power, but merely to the brilliancy of the image from the greater number of rays diverging from it. But by using two plano-convex lenses, so combined as to be like one glass, the magnifying power and field of view are increased.

The astronomical telescope differs from the Galilean in having a convex eye-glass, by which the magnifying power is increased. The two lenses N S and L E (fig. 237) are placed at the opposite end of two tubes, the one sliding within another; the former of which is called the *object-glass*, from being next the object A R; and the latter the *eye-glass*, from its being next the eye, placed at I: the lenses are of unequal focal length, but so fixed that they have a common axis. A R is the object supposed to be at a great distance, N S the object-glass, behind which and a little beyond its focus will be the diminutive

inverted image of the object viewed at *r s*. L E is the object-glass, and as it magnifies, the image is viewed under the angle I *y z*, and is seen as at the dotted arrow. Thus these objects

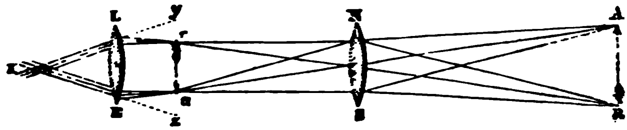


Fig. 237.

are seen in an inverted position, which is of no consequence in astronomical observations. It is usual to fix the object-glass at the end of a tube longer than its focal distance, and to place the eye-glass in a small tube, which must slide out of and into the larger tube, for the purpose of adjusting it to objects at different distances.

The magnifying power of this kind of telescope, named refracting, is found by dividing the focal distance of the object-glass by the focal distance of the eye-glass; thus, if the focal distance of the object-glass be 150 inches, and it admit of an eye-glass whose focal distance is 3 inches, the 150 divided by 3, gives 50 for the number of times the telescope will magnify the diameter of an object.

When two additional lenses are added to the astronomical telescope, it then becomes a terrestrial telescope, or perspective glass, and objects are seen by it in their right position.

A R (fig. 238) is the object, from which the rays of light

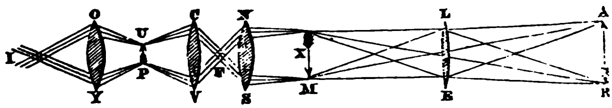


Fig. 238.

pass through the object lens L E, and form the image M at X, which is the focus of the lens N S, from whence, having crossed at the focus F, they pass on to the next glass C V, and in passing it they are converged to the points in its other focus, where they form an erect image U P; and as this is the focus of the eye-glass O Y, and as the eye when at I is at the same distance

on the other side, the image is seen through the eye-glass in this upright position. As the three eye-glasses have all their focal distances equal, the magnifying power is found by dividing the focal distance of the object-glass by the focal distance of any of the eye-glasses.

In the year 1663 a young man of the name of James Gregory published a work pointing out the defects of the refracting telescopes, and proposing the substitution of a metallic speculum for the object-glass, on which to receive the image and reflect it towards a small speculum of the same material. Want of means or mechanical ability caused this idea to remain dormant until 1672, when Sir Isaac Newton, finding that the errors arising from the refrangibility of light were greater than those from reflexion, formed two reflecting telescopes on the principle, though not quite the plan of Gregory. These were only six inches long, but equal to a refractor of six feet; the reflecting telescope admitting of an eye-glass of a shorter focal distance than a similar refractor, its magnifying powers are increased.

In the Gregorian telescope M M (fig. 239) are the concave

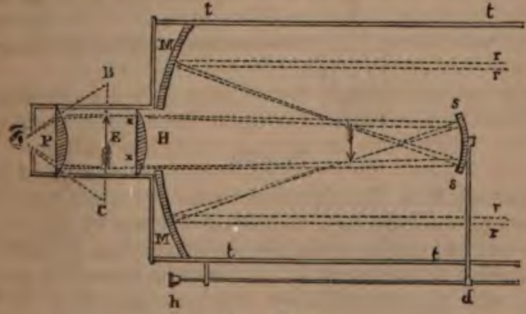


Fig. 239.

metallic mirrors forming together a speculum; the small arrow represents the inverted image formed by it of the object proceeding from rays r r r r. This image is reflected again by another small concave speculum *s s* placed before the great speculum, and in its axis, and thus it forms the erect image E, which to an eye at P will appear magnified. The small speculum is adjusted by means of a screw and rod h d, which is fitted on

the outside of the body, t t t t. The image might have been viewed and magnified by the convex eye-glass at P alone, but it is generally preferred to receive the converging rays upon a lens H, called the field-glass, which hastens their convergence and forms the image in the focus of the lens P, by which they are magnified and rendered more distinct. This telescope possesses the advantage of being capable of direction in the line of sight towards the object, as well as the objects being seen upright; but from the hole in the middle of the object-speculum, the quantity of light is diminished, and the objects less distinctly seen.

In the Newtonian reflecting telescope, the large concave speculum *c c* (fig. 240) is placed at the end of the tube; the

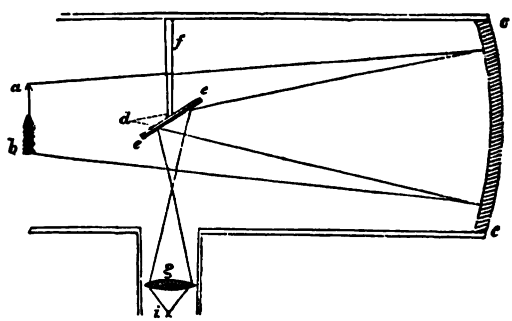


Fig. 240.

rays proceed from the object *a b* to the speculum *c c*, and are reflected to the mirror *e e*, supported or hung by *f*; and from thence at right angles to the double-convex lens *g*, where they are refracted to the eye at *i*. If the small mirror *e e* was dispensed with, the rays from *n o* would converge to *d*, at which place the eye of the observer would see the image of the object *a b*; but as his head would intercept a portion of the rays, the small speculum *e e*, and convex lens *g*, are arranged as in the diagram.

The gigantic telescope at Slough near Windsor was after several failures completed by Sir William Herschel in 1789, and magnifies 6450 times. With this a satellite of Saturn was instantly discovered, and also a new planet, which received

the name of Herschel. The tube of this remarkable instrument is 39 feet 4 inches long, its diameter 4 feet 10 inches. The great metal mirror is 49½ inches in diameter, but the polished surface only 48 inches, its thickness 3½ inches, and its weight before being polished 2118 lbs. It magnifies objects nearly 7000 times, and brought 36,500 times as much light into the eye as would have been derived, without such aid, from the object. At the open upper end of the tube which is directed to the heavens, the observer sits with his back to the object investigated, which he sees by rays reflected from the great mirror through the eye-glass at the opening on one side of the tube (fig. 241); *s* is the speculum set at such an

Fig. 241.

inclination to the axis of the tube which contains it, that the inverted image *a* which is formed of an object *b c* is projected towards the edge of the tube: *d* is the eye-glass through which the eye *e* would see the enlarged image *f g*.

A triumph in reflecting telescopes has been accomplished by the energy, genius, and wealth of Lord Rosse; the description of which wonderful piece of scientific mechanism we take from the 'Illustrated London News.'

"The diameter of the large speculum is 6 feet, its thickness 5½ inches, its weight 3¾ tons, and its composition 126 parts of copper to 57½ parts of tin; its focal length is 54 feet: the tube is of deal; its lower part, that in which the speculum is placed, is a cube of 8 feet; the circular part of the tube is at its centre 7½ feet diameter, and at its extremities 6½ feet. The telescope lies between two stone walls, about 71 feet from north to south, about 50 feet high, and about 23 feet asunder. These walls are, as nearly as possible, parallel with the meridian.

"In the interior face of the eastern wall, a very strong iron arc, of about 43 feet radius, is firmly fixed, provided, however, with adjustments, whereby its surface facing the telescope may

Fig. 242.—Lord Rosse's Telescope.

be set very accurately in the plane of the meridian—a matter of the greatest importance, seeing that by the contact with it of rollers attached to one extremity of a quadrangular bar, which slides through a metal box fixed to the under part of the telescope tube, a few feet from the object end of the latter, whilst its other extremity remains free, the position of the telescope in the meridian is secured, or any deviation from it easily determined; for on this bar lines are drawn, the interval between any adjoining two of which corresponds to one minute of time at the equator. The tube and speculum,

including the bed on which the latter rests, weigh about 15 tons.

"The telescope rests on a universal joint, placed in masonry about 6 feet below the ground, and is elevated or depressed by a chain and windlass; and although it weighs about 15 tons, the instrument is raised by two men with great facility. Of course, it is counterpoised in every direction.

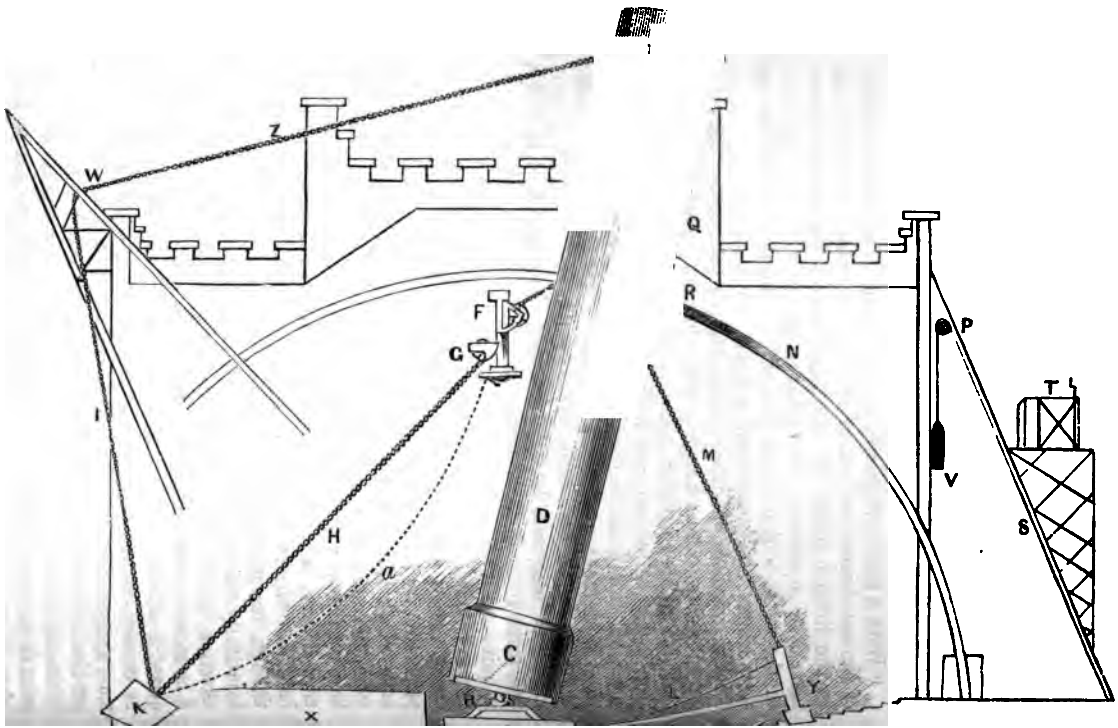
"The observer, when at work, stands in one of four galleries, the three highest of which are drawn out from the western wall, whilst the fourth, or lowest, has for its base an elevating platform, along the horizontal surface of which a gallery slides from wall to wall by machinery within the observer's reach, and which a child may work.

"When the telescope is about half an hour east of the meridian, the galleries hanging over the gap between the walls present to a spectator below an appearance somewhat dangerous; yet the observer, with common prudence, is as safe as on the ground, and each of the galleries can be drawn from the wall to the telescope's side so readily, that the observer needs no one else to move it for him.

"The telescope lying at its least altitude can be raised to the zenith by the two men at the windlass in six minutes: and so manageable is the enormous mass, that, by giving the right ascension and declination of any celestial object between these points, the object can be brought into the field of the telescope within eight minutes from the first attempt to raise it.

"When the observer has found the object, he must at present follow it by rackwork within his reach. As yet it has no equatorial motion, but it very shortly will; and at no very distant day clockwork will be connected with it, when the observer will, whilst observing, be almost as comfortable as if he were reading at a desk by his fireside.

"Fig. 243 is a sectional view taken inside of the eastern wall, with all the machinery. A is the mason-work in the ground; B the universal joint, which allows the tube to turn in all directions; C the speculum in its box; D the tube; E the eye-piece; F the moveable pulley; G the fixed one; H the chain from the side of the tube; I the chain from the beam; K the counterpoise; L the lever; M the chain connecting it with the tube; Z the chain which passes from the tube to the windlass over a pulley on a truss-beam, which runs from W to



Z
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the same situation in the opposite wall—the pulley is not seen; X is a railroad on which the speculum is drawn either to or from its box—part is cut away to show the counterpoise. The dotted line *a* represents the course of the weight R as the tube rises or falls; it is a segment of a circle, of which the chain I is the radius.

"With a little attention to these several points, the working of the machinery will be easily comprehended. The weight on the lever L sinks only 15 feet under the horizontal position; it then rests on the ground, and is, of course, no load on the tube, which is, when this happens, 30 degrees above the horizon. Below this point the tube is sufficiently heavy to descend when the windlass unrolls the chain. Then suppose the tube makes the angle of 30 degrees with the horizon, and that it is required to elevate it, the windlass is turned, and the chain being shortened, the desired effect is produced; but the labour of this would be immense if the counterpoise K did not assist: this nearly balancing the tube, leaves but little exertion to be made at the windlass. However, the weight of the tube, according as it ascends, is gradually becoming less and less, until it produces no strain at all on the windlass when it is quite upright. This must evidently be the case from the first principles of mechanics; for making the tube a lever, the length of its arm continually decreases as it approaches the perpendicular; therefore, if the counterpoise continued the same weight on the tube towards the end as it was in the commencement of the ascent, it would be too heavy, and would keep it in its perpendicular position. In fact, the counterpoise must become lighter as gradually and as evenly as the tube itself, in order to continue to be just the same support to it all through its movement. The plan adopted to effect this is beautifully simple: a weight, hanging freely in a perpendicular direction, exerts its greatest force on the suspending point; if it be moved from the perpendicular, as much power as is required to effect this is taken off from the same point; as will be evident to any person pushing aside a hanging body, he must apply a certain degree of force to keep it out of its perpendicular position; and this might be mathematically proved to amount to exactly the degree of weight that is taken off the point from which the body hangs. Now, it will easily be seen, when the tube is ascending and losing its weight, also lengthen-

ing the chain H, that on account of the chain I, whose length is always constant, the counterpoise K is moving from the perpendicular position under G, and therefore losing its power on the tube, and approaching the perpendicular under W, and for this reason transferring all its weight to the fixed chain I; when the tube passes the perpendicular, the chain H is again shortened, and the counterpoise begins once more to draw it back; so that the action of this tends to keep the tube always upright to whatever side it may point, and its power is always equal to the varying weight. Under these circumstances, we see how easily and evenly the windlass can elevate the telescope and turn it to the north; but when it arrives there it must be brought back again; and this is accomplished by the lever L. As we have seen that the action of the tube and counterpoise is so regulated, that in all positions the weights, although always changing, are equal to one another, so must the weight of the lever vary with its position in order to be a perfect balance on the tube; and this it evidently does. We said, that when the tube was perpendicular the weight on the lever is most effective, for it is at the furthest distance it can be from the support; it therefore pulls down the tube when the windlass is unrolled; but we saw that the tube as it descends increases its weight; so that if the lever continued acting with the same power with which it commenced, the weight of both would be constantly increasing; this is prevented by the lever losing its force as it falls; for the weight thereby, of course, approaches the support, and cannot be so active; but the approach to the support by its descent is so regulated to the increasing distance of the end of the tube in *its* descent by the chain M, that in the same degree as the latter gains weight the former loses it; and in this manner there is a constant equilibrium kept up between them. When the tube reaches within 30 degrees of the horizon the lever rests on the ground, and the tube is thence able to descend by its own weight. When the tube points to the north, the lever is elevated above the horizon, and has not, of course, so much power as when it coincided with it; but it is in this case helped by the counterpoise K, which always tends to bring the tube to the perpendicular. This continues to help it until it becomes itself sufficiently able, from its horizontal position, to *do all* the work; it then commences opposing it; but it now

has the help of the increasing weight of the tube itself; and so all the parts are elegantly blended into one another with the most perfect concord and efficiency.

"The manner in which the tube is moved from wall to wall is accomplished by the ratchet and wheel at R, in fig. 243; the wheel is turned by the handle O, and the ratchet is fixed to the circle in the wall. The ladders in front, as shown in fig. 242, enable the observer to follow the tube in its ascent to where the galleries on the side-wall commence; these side-galleries are three in number, and each can be moved from wall to wall by the observer, after the tube, the motion of which he also accompanies by means of the handle O."

It has been shown, that when light is bent by a convex lens, there is a slight separation of the prismatic colours, which tinges the extremities of the objects viewed; this causes a serious indistinctness, which Sir Isaac Newton feared would prevent the perfection of the telescope. To remedy this, Euler, the Swiss philosopher, from an examination of the human eye, recommended the adoption of a double object-glass of two lenses, having water between them. This led to experiments by Mr. Dollond, a celebrated English optician, to discover if possible a transparent medium by which there would be refraction without colour; and as different kinds of glass were found to have different dispersive and refractive powers, it was thought by combining two all the colours might be refracted equally. For this purpose Dollond thus composed his lenses, the convex one of crown-glass and the concave of flint-glass (fig. 244). The refracting angles were inversely as the dispersive powers of the respective glasses; the concave lens preventing the dispersion of colour by the convex, while there was sufficient convergence of the rays for the formation of the image, and thus the desideratum was accomplished. Fig. 245 better explains the arrangement necessary to correct the imperfection spoken of.

Fig. 244.

In this figure, L L is a convex lens of crown-glass, and *l l* a concave one of flint-glass. A ray of the sun L falls at F on the convex lens, which will refract it exactly in the same manner as the prism A B C, whose faces touch the two surfaces of the lens at the points where the ray enters and quits it. The

solar ray S F, thus refracted by the lens L L, or prism A B C, would have formed a spectrum P T on the wall, had there been no other lens, the violet ray F V crossing the axis of the lens at V, and going to the upper end P of the spectrum, and the red ray F R going to the lower end T. But as the flint-glass lens *l l* or the prism A *a* C, which receives the rays F V, F R at the

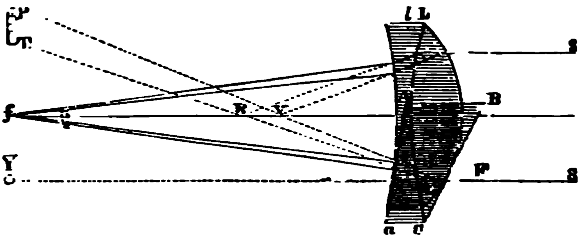

Fig. 245.

same points, is interposed, these rays will be united at *f*, and form a small circle of white light; the ray S F of the sun being now refracted without colour from its primitive direction S F Y into the new direction F *f*. In like manner, the corresponding ray S′ F′ will be refracted to *f*, and a white and colourless image of the sun will be there formed by the two lenses.

In this combination of lenses, it is evident that the chromatic aberration of the flint-lens corrects to a considerable degree that of the crown one, and, by a proper adjustment of the radii of the surfaces, it may be almost wholly removed. Dollond named his telescopes achromatic, from two Greek words meaning without colour.

Dr. August gives the following method of estimating the magnifying power of telescopes, and the extent of their field of vision. The magnifying powers may be estimated pretty nearly by looking at the same object with one eye through the telescope and with the other naked, and comparing the apparent magnitudes of the two images. This measurement may be rendered still more exact if any kind of telescope, except a Galilean, be pointed towards a clear part of the sky, and a leaf of thin paper or transparent horn be held behind the last eyeglass, at the spot where the eye is ordinarily placed; a bright, strongly defined luminous circle will be visible on the transparent plate, supposing it to be held at the right spot.

Measure its diameter as accurately as possible, and then measure the width of the object-glass, using the same scale in each case; divide its diameter by that of the luminous spot, and the quotient will give the magnifying power of the telescope.

The luminous circle is, in fact, an image of the object-glass itself, whence it may be proved that it is contained in the diameter of the object-glass as many times as are equal to the magnifying power of the telescope. The object-glass may be taken out, and a rim, or annulus, having exactly the same opening as will be equal to the circle of light, put in its place; the quantity of light will be increased, and the images of objects rendered more distinct by this alteration. Ramsden contrived a little instrument, to which he gave the name of dynamometer, for measuring the powers of telescopes.

The field of a telescope may be estimated by comparing its diameter with the apparent diameter of some object viewed through the telescope. In the choice of an object, one should be selected whose apparent diameter is already known to us; that of the sun or moon will answer the purpose well; they are both equal, or very nearly so, the apparent difference amounting only to half a degree, or 30 minutes. Or the field may be measured by directing the telescope to some star in or very near to the equator, care being taken that it shall pass over the *middle* of the field, and then count the number of seconds which elapse during its passage: four seconds of time will make an angle of one minute for the field of vision. For a full description of the uses and wonders of the telescope, we beg to refer to Hind's 'Astronomy,' forming one of this series of educational books, and of which a new edition is in the press.

Instruments in Use in an Astronomical Observatory.

The position of a body on a plane surface, as this sheet of paper, is defined by its distances from two definite points, or two fixed lines, generally at right angles to each other, in the same plane. In a similar manner, the position of a body on a round or spherical surface may be defined by means of its angular distances from two points, or from two points situated in two great circles of the spheres, as the longitude of a place on the earth's surface is its angular distance from an assumed meridian, and its latitude the angular distance from the equator. The intersection of these two lines determines the exact posi-

tion of any proposed point on the earth's surface; so, in like manner, the right ascension of a heavenly object is its angular distance measured along the equator from that point in the heavens where the plane of the ecliptic intersects that of the equator, and which point is called the first point of Aries.

The declination is the angular distance of the object from the equator, and is north or south according as the position of the object is north or south of the equator; the intersection of this distance with that of the right ascension indicates the place of the heavenly body. The angular distance from the pole is called the polar distance, and if measured from the North Pôle, the north polar distance. The pole is a better point to measure from than the equator, as there is no consideration respecting north and south. It is the main business of an astronomical observatory to determine these two elements, viz. right ascension and declination, or north polar distance of the sun, moon, planets, stars, and comets.

Perhaps it would be well to speak here of the instruments employed, and to describe the method of their use.

If we visit an observatory, we shall find in one apartment the transit instrument, which is devoted to the determination of one of these elements; and in another apartment the mural circle, which instrument is devoted to the determination of the other element.

The transit instrument (fig. 246) consists of an achromatic telescope, to which is firmly fixed a doubly conical and horizontal axis, at right angles to the optical axis of the telescope; the extremities of the axis are even-turned pivots of steel or bell-metal, which rest on angular bearings called Y's, firmly attached to the inner faces of two solid stone piers, in such positions that the axis of the instrument is horizontal, or nearly so, and such that the telescope can move in the meridian only, or very nearly so. The axis has two adjustments, one for making it horizontal, and the other for adjusting the telescope to the meridian. Two circles are placed near the eye end of the telescope, furnished with verniers, to which a small level is attached, the purpose of which is to enable the observer to direct the telescope to any meridian altitude.

On looking into the telescope, a set of vertical lines (technically called wires) is seen, five or seven in number, and crossed at right angles by one or two horizontal wires. These lines

are fine cobwebs, or fine threads fixed in the telescope to a wire-plate, very near the eye: the stars are seen to pass them successively from one to the other, and across the field.

Fig. 246.

Near the transit instrument is placed a clock, called the Transit Clock, adjusted to sidereal time, by making its indications of twenty-four hours correspond, or very nearly so, with the interval of time between the consecutive passages of the same star over the meridian; one duty of the transit instrument is to regulate the clock. On looking at an object through a telescope, the object itself is not seen, but only its image formed at the focus of the object-glass. This image, in respect

to the object, is inverted; and thus the upper or lower limb of the sun, moon, or planets, &c., appears the lower and upper respectively, as seen through the telescope; also the direction of their motions is reversed, causing all heavenly bodies to appear to move from west to east. This is explained by the following diagram:—

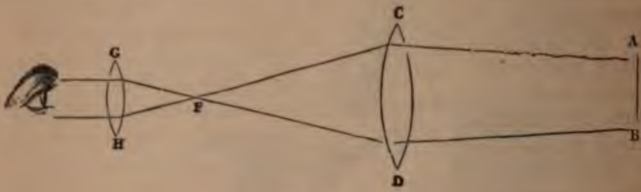

Fig. 247.

Let A B (fig. 247) be a distant object, C D an object-glass, F the focus, G H the eye-glass. A ray of light proceeding from A B falls on the object-glass, is refracted or bent by it, and turned in the direction F. The ray from A proceeds as above described, and meets the eye-glass at its lower part; in like manner that at B meets the eye-glass at its higher part: thus the image of the object A B is inverted. In like manner rays proceeding from the sides of the object are inverted, and hence the motions of the heavenly bodies are reversed.

On looking at a star with the naked eye (to the south), the star passes from left to right, but on looking into the telescope, the image of the star is seen to enter at the right hand, and to pass over the wires in succession from right to left. The motion of all stars, as magnified by the telescope, is sensible; those situated near the equator move very quickly.

On a star approaching the meridian, the observer having directed the telescope to that part of the heavens over which it will pass, looks in and sees both the wires and the image of the star. He then listens to and counts the beats of the clock recording the second and tenth part of the second in a recording book, held in his hand, as the star passes each of the separate wires (fig. 246). By taking the mean or average of these times, the time is determined when the star was on the meridian. In a similar manner he observes the sun, *moon*, planets, &c., and thus finds the time of the clock at

which they severally pass the meridian. If now the instrument and the clock were all without error, these times would be the right ascensions of the objects observed, conditions, however, which are never fulfilled; to the times thus found small corrections are to be applied, for the deviations of the instrument from perfect adjustment, and for clock errors.

The clock time at which a well-known star passes the meridian being thus found, the error of the clock is ascertained by comparing this time with its tabular right ascension, published in the 'Nautical Almanac,' and based upon all the observations made upon that star for many years. Such stars are called clock stars; and the difference found between the clock time and the right ascension of the star gives the error of the clock, and so true time is found.

If the clock be so adjusted that the same time be shown at two consecutive passages of the same star, there is no clock-rate, and the error of the clock would be applicable to every object observed between these times. But if the clock does not exactly show 24 hours in this interval, the difference from 24 hours becomes known, and is the clock's daily rate; and we can calculate a due and proportionate part of this rate at the time of every observation, and thus obtain the same results as though the clock were accurately adjusted. The error of the clock becomes thus known at the time of every observation, and by its application to the clock time, the right ascension is determined.

In an adjoining apartment, in an observatory, will be found the mural circle. The instrument is in appearance like a wheel: A (fig. 248) is a stone pier, several feet in thickness, upon which it is supported. The circle turns round an axis which passes through the pier; its edge, or cylindrical rim, is divided into 360 equal parts, or degrees, and each degree is subdivided into twelve equal parts, and therefore into five minutes of arc; thus the outer rim has engraved upon it 4320 lines, on a band of platinum. The accurate division of this band is a very severe test of the ability of the instrument-maker. To the circle a telescope is attached, which, from time to time, can be moved on the circle, so that different parts of its limb may be made to measure the same arc in the heavens. The telescope is furnished with a system of wires similar to that in the transit instrument. Its eye end is also

furnished with a wire micrometer—an apparatus adapted to the measurement of small angular spaces.

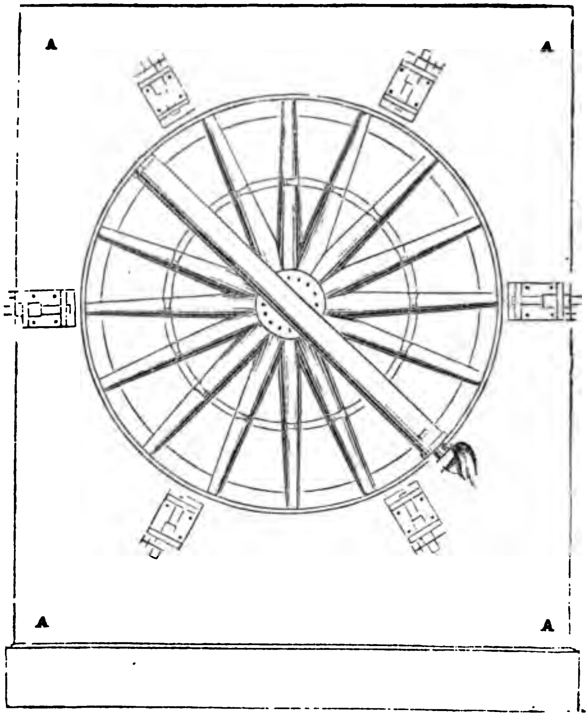

Fig. 248.—The Mural Circle.

The micrometer consists of a moving frame, across which one or more wires are stretched, as shown in figure 249. The whole is moved by the screw, and kept in position by an opposing spring *b*; the screw carries a head divided into a certain number of parts (usually 60 or 100), one side of the box in which it is enclosed being removed, to show its action.

The mural circle, with its telescope, turns round on an axis which passes through the pier, which faces to the east or west; and consequently, like the transit instrument, can move only in

the meridian; objects, therefore, can be seen only whilst they pass the meridian.

On the face of the pier are firmly attached six microscopes placed equidistant and around the circle. These microscopes are directed to the several divisions on the band of platinum; they are each furnished with a wire micrometer, the heads of which are divided into sixty parts, as shown in the accompanying figure, and are so adjusted that five turns of the micrometer screw carries the cross wire from one division on the limb to the next; as these divisions are separated by five minutes of arc, each revolution of the screw corresponds to one minute of arc. The micrometer head, carried by the screw, is divided into sixty parts, and therefore each part corresponds to one second of arc; the space between two of the parts the observer mentally subdivides into ten parts, and thus measures to the tenth part of a second of arc are noted. On looking through the microscopes at the divisions on the limb, the following is the appearance shown. The teeth on the left hand form what is technically called the comb-plate, and five of its notches correspond to the space of five minutes on the limb. The divisions on the limb of the circle are shown by the short horizontal lines; opposite to one of these divisions to the right is a single dot, opposite to another are two dots, and to a third three dots: these respectively show the value of those divisions to be fifteen minutes, thirty minutes, and forty-five minutes distant from the preceding whole degree. In reading, one angle of the cross wires

Fig. 249.

of the micrometer is bisected by one of the divisions on the limb, as shown in fig. 250.

The use of the several microscopes is to avoid the error consequent on the use of one only, which might be caused by faulty divisions or imperfections in the form of the circle.

Fig. 250.

When a star or object is approaching the meridian, the observer directs his telescope to that part of the heavens over which it will pass, and bisects the star by the micrometer horizontal wire when it is situated on or near the middle wire, then by reading the several microscopes he ascertains the reading of the circle when the telescope was directed to this star. To render this observation available, it is necessary to know the reading of the circle when the telescope is directed to some definite place, as the horizon, the zenith, or the pole: this point from which to measure is found by the use of a trough of mercury, and is as follows:—The mercury is so placed that on the star approaching the meridian its reflected image can be seen through the telescope, and an observation made as above described; by the time the star has passed the meridian, the telescope may be directed to the star itself, and a second observation made. In the former observation the telescope was directed to a point as much depressed below the horizon, as in the latter it was directed to a point elevated above the horizon; and from these observations the reading of the circle, when the telescope is directed to the horizon, may be found. If to this reading 90° be applied, the reading will be found when the telescope is directed to the zenith. If this be used as a starting-point from which to measure, then the difference between this reading and all others will give the apparent angular zenith distance of the several objects observed. It is necessary, however, to remember that every object in the heavens appears to be too high, in consequence of refraction.

The theory of refraction it may be as well to refer to in detail once more. A ray of light as proceeding from a star, is bent, so as to form a smaller angle with a perpendicular to the surface of the earth, and this bending is increased till the ray reaches the earth's surface, and the object is seen in the direc-

tion of the last bend of the ray, causing all objects to appear higher than they really are. This will be better understood by reference to the figure 251.

Let A B, C D, E F, G H, and I J represent portions of concentric strata of atmosphere. A ray of light proceeding from a star S, meets successively the several strata, and is continually bent at a different angle; till, finally, it is seen in the direction of S O, and the object seems to occupy the position S′. The increase of density of the atmosphere on approaching the earth follows the law of continuity; so that the ray, in traversing the atmosphere, enters at every instant into a denser medium; its true path is therefore curved, as shown in the following diagram, where O represents the place of an observer on the surface of the earth, Z his zenith, H his horizon, S the place of a star; the path of the ray will be S A O, and the star will be seen in the direction of O S′, and not O S; the difference between

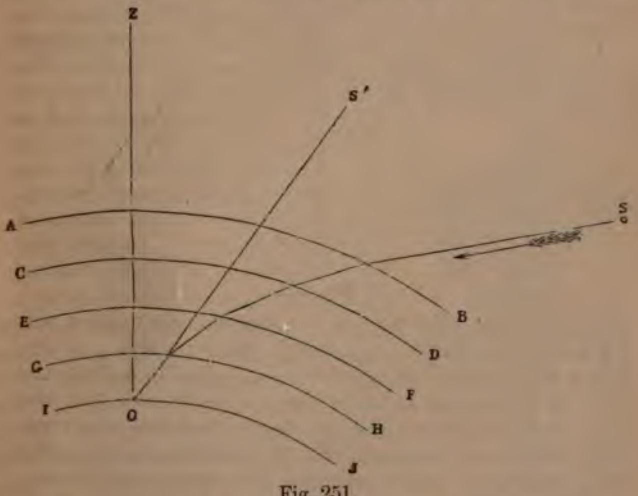

Fig. 251.

the angles S O H and S′ O H is what is called atmospheric refraction, the amount of which is to be calculated for every observation, to reduce it to what it would have been had there been no atmosphere.

By determining the elevation of the pole star, and other stars situate near the pole, above the horizon, both when above and below the pole, the true place of the pole may be found; and consequently the north polar distance of all objects can be ascertained by adding to the true zenith distances the angular distance of the pole from the zenith, or the co-latitude of the place (fig. 252).

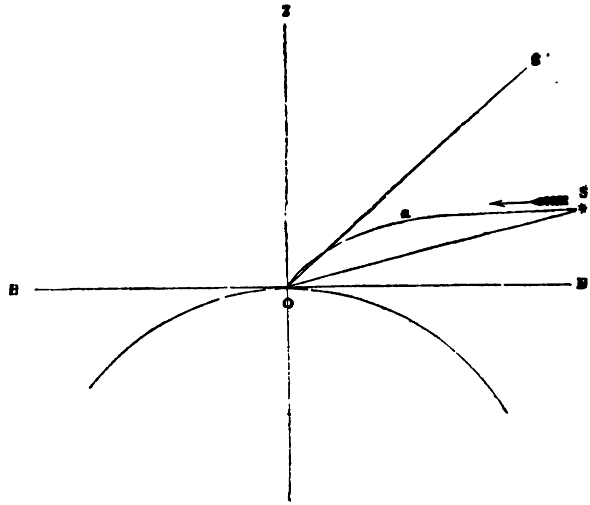

Fig. 252.

The declination is found by taking the difference between the north polar distance and 90°. Thus, by the use of the transit instrument, one of the two elements to determine the place of a celestial object is obtained, and by the use of the mural circle, the other necessary element is determined. These being found—in the case of the old planets, are compared with their calculated places, and the differences between them, called errors of tables, form the basis of future calculations to free the tables of such errors. In the case of new planets and comets, their orbits are, in the first place, calculated from the observed right ascensions and north polar distances; and the results of such calculations remain for comparison with future

observations, with the view to the improvement of the elements of their orbits.

The Gyroscope.—The phenomena of rotatory motion, and that of planetary motion, known to astronomers as *precession* and *nutation*, have recently been aptly illustrated by the *gyroscope*, an instrument constructed, and more recently modified, by M. Foucault.

The name of the instrument is derived from two Greek words, the one denoting *to turn*, and the other *to view*. Every particle of a disc revolving on an axis endeavours, or has a tendency, to fly therefrom, on account of centrifugal force; but diametrically opposite are the similar particles exerting the same influence on the axis. This force, influencing the axis all around, causes the rotating body to tend to preserve its plane of rotation, and with the size of the rotating body it requires a considerable increasing force to displace its axis. This fact being well understood, presents the key to the explanation of all the experiments that the instrument is capable of exhibiting.

When the disc B (fig. 253) is rapidly rotating, and the stand D is turned, the axis I I of the disc B will constantly point to the same direction. The friction of the vertical axis must be considered as nothing; therefore, the tendency of the disc to keep the plane of rotation is not impeded, and no effect is produced upon the same; and similar is the case when the gyroscope is taken by the stand and moved in any direction. Even an inclination of the stand D in the plane of the axis will produce no effect: *i.e.* if the axis stand horizontally, it will continue to do so; but, attempting to turn the semicircle C to the right or to the left hand, the axis of the disc will take up such a position as to coincide with the new axis which the experimenter is endeavouring to confer. In such instance two forces are simultaneously summoned into ac-

Fig. 253.

tivity—the force of the hand, and the tendency of the disc to keep the plane of rotation; and the former being infinitely greater than the latter, the disc can only move in the prescribed direction.

If the semicircle C and the gymbal A be connected by means of a milled-headed screw K, no resistance will be felt either way. The same will be the case in one direction if the quadrant G be attached to the semicircle C; but then some other phenomena occur, because the two axes are at right angles with each other. The impossibility of the one force exerting its influence, leaves the other force free to act, as though the other were not in existence; but the force is only apparently lost, for a slight push against the semicircle will cause the instrument, as it were, to revolve round the stand on the table; that is to say, the instrument lifts a little from the table, and plays around the surface of the stand. In this manner the force that is stopped by the quadrant shows again at the bottom of the stand.

If a weight P be suspended in the continuation of the axis on the screws L L, it will be unable to draw the same down, but will impart a slow horizontal motion to the spindle M. This is a beautiful and instructive experiment; if the rotation of the disc be stopped, the weight will draw it down; if the horizontal motion of the semicircle be stopped, the weight will draw the disc down, however rapid may be the rotation; *i. e.* remove the possibility that the compounded effect can take place, and the one that is left at liberty will act as though the other had no existence.

This remarkable fact bears analogy to some of the most important truths of the 'Mécanique Céleste.' If the rotation of the earth were stopped, it would fall upon the sun; and if the possibility of the orbitual revolution of the earth around the sun were stopped, it would fall upon the sun, notwithstanding its axial rotation.

When the ring A with the rotating disc B is detached from the semicircle C, by lifting the screw E, and suspended by a string on the screw-head L, the disc will stand horizontally, and whilst so suspended it will revolve slowly round the suspending string as a centre of motion; the tendency of the rotating body to keep the position of its axis is so great as to *resist* the action of gravity on the mass, even if an extra

weight be suspended on the opposite screw-head L. Another modification of the experiment is to let the arrangement rest on a hook H in the continuation of the axis in a hollow attached to the stand. If the weight be changed to the opposite side, the semicircle will turn to the opposite direction.

The rotating disc, freely moved in all directions by the hand, will furnish a very forcible proof of the resisting force which is opposed to any endeavour to change the plane of rotation; and if placed with the screw-head L on the table, it will keep itself upright like a spinning-top; and if the friction between the screw-head and the table be greater than between the point on which the axis turns, the ring will remain stationary.

Close to the axis, on the disc, is a milled wheel, which can serve as a means of calculating the number of revolutions in a second. If a card be held against it, a musical tone is produced, which will rise higher with the rapidity of the rotation: if the note be taken, and the number of the teeth in the milled wheel be known, the number of the rotations can be calculated by an acoustical table.

[For an analytical investigation of the phenomena exhibited by the gyroscope, the reader is referred to a paper by Mr. John Bridge, in the 'Philosophical Magazine' for November 1857.]

The Microscope.

The telescope opened out to man's view a system of worlds and an extent of space almost too large to be grasped by his intellect. Another optical instrument, the microscope, has revealed worlds in miniature, so immense in numbers, so perfect in organization, surrounding man in all space and matter, enjoying their existences and performing all the duties imposed upon them by the laws of nature, and yet so small as to be hidden from the unaided eye. By the microscope also the minutest structure of all matter is seen, and nothing remains hid from its piercing scope.

The word microscope means, to see what is small. The most powerful instruments resemble in construction an inverted telescope; but as the latter forms an image of a distant object smaller than itself in proportion as the distance of the image from the glass is less, the former having a small object placed

near the focus of the object-glass produces a more distinct image, as much larger than itself as the image is more distant, for which purposes there is a proper adaptation of object-glasses, that of the telescope being generally large, that of the microscope very small. Thus, if the focal distance of an object-glass in a microscope be one-eighth of an inch, and the object be so situated that its image is formed at six inches, the image will be of a diameter forty-eight times as great as the object; and when seen through an eye-glass of half an inch focus, it will seem magnified twelve times more, or 30,000 times larger than the real size of the object.

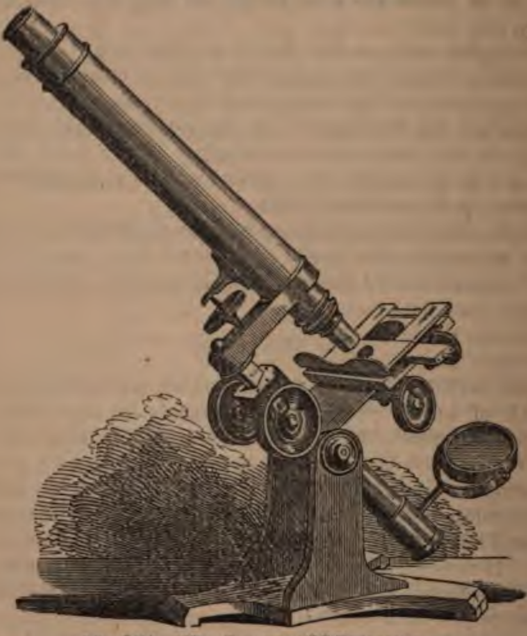

Fig. 254.—The Compound Microscope.

As we cannot see small objects nearer than about six inches, we make use of glasses to look at them nearer than this distance, because the apparent size of objects is measured by the angle under which they are seen by the eye, which

of course must be greater or less as the object is nearer or more distant; thus, if A R (fig. 255) and O W be two equal objects, one, O W, at the distance of "distinct vision" from the eye, six inches, and the other, A R, at half that distance, that we may be able to see A R we must place a convex lens between it and the eye, to cause the rays proceeding from the object to pass out of the lens, and thus converge to a focus on the retina of the eye.

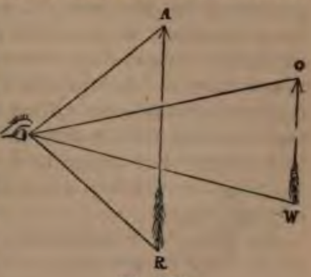

Fig. 255.

When an object is too near the eye (fig. 256), the rays are too divergent to admit of distinct vision; hence, by applying a convex lens (fig. 257), the rays are rendered parallel to the eye, and the object distinctly visible; the convex lens becomes a single microscope.


Fig. 256.

Microscopes are of three kinds, the single, compound, and solar.

The magnifying power of the single microscope is found by dividing the distance a person sees at best, by the focal distance of the lens; thus, if a person sees an object well at 6 inches, and the focal distance of the lens be $\frac{1}{10}$th of an inch, it is said to magnify lineally, or in one direction, 60 times, and the surfaces will be magnified 60 times 60, or 3600 times.


Fig. 257.

A compound achromatic microscope is a beautiful piece of workmanship, possessed of all the appliances of mechanical science, and lately brought to a wonderful state of perfection (fig. 254). It consists of two compound lenses, by one of which, the object-glass, an image is formed within the tube of the microscope; which image is viewed instead of the object, as re-magnified by the second lens, the eye-glass.

A section of a modern compound achromatic microscope, as manufactured by our best makers, is represented by fig. 258, where *o* is an object; above it is seen the triple achromatic object-glass, and in connexion with it *e e*, *f f*, plano-convex

lenses, *e e* being the eye-glass, and *f f*, the field-glass, and between them at *b b* a dark spot or diaphragm. The course of the light is shown by three rays, drawn from the centre, and three from each end of the object *o*; these rays, if not prevented by the lens *f f*, or the diaphragm at *b b*, would form an image at *a a*; but as they meet with the lens *f f* in their passage, they are converged by it and meet at *b b*, where the diaphragm is placed to intercept all the light except that required for the formation of a perfect image; the image at *b b* is further magnified by the lens *e e*, as if it were an original object.

Fig. 258.

Mr. Lister's investigations in the year 1829, made for the purpose of improving and correcting the imperfections of the object-glasses of the compound microscope, led to the most important results.

In the improved combination the diameter is only sufficient to admit the proper pencil; the convex lenses are wrought to an edge, and the concave have only sufficient thickness to support their figure: consequently the combination is the thinnest possible, and it follows that there will be the greatest distance between the object and the object-glass. The focal length is $\frac{1}{8}$th of an inch, having an angular aperture of 60°, with a distance of $\frac{1}{25}$th of an inch, and a magnifying power of 970 times linear, with perfect definition of the most difficult test-objects.

The quality of the definition produced by an achromatic compound microscope will depend upon the accuracy with which the aberrations, both chromatic and spherical, are balanced, together with the general perfection of the workmanship. Now in Wollaston's doublets and Holland's triplets there are no means of producing a balance of the aberrations, as they are composed of convex lenses only; therefore the best thing

that can be done is to make the aberrations a minimum. The remaining positive aberration in these forms produces its peculiar effect upon objects, which may lead to misapprehension of their true structure; but with the achromatic object-glass, where the aberrations are correctly balanced, the most minute parts of an object are accurately displayed, so that a satisfactory judgment of their character may be formed. When an object has its aberrations balanced for viewing an opake object, and it is required to examine that object by transmitted light, the correction will remain; but if it is necessary to immerse the object in a fluid, or to cover it with glass, an aberration arises from these circumstances which will disturb the previous correction, and consequently deteriorate the definition: and this defect will be more obvious from the increase of distance between the object and object-glass.

The triple achromatic combination constructed on Mr. Lister's improved plan, although capable of transmitting large angular pencils, and corrected as to its own errors of spherical and chromatic aberration, would, nevertheless, be of little ssrvice without an eye-piece of peculiar construction.

"It is difficult," says Mr. Ross, "to convey a perfect idea of the beautiful series of corrections effected by the eye-piece, and which were first pointed out in detail in a paper on the subject, published by Mr. Varley, in the fifty-first volume of the 'Transactions of the Society of Arts.' The eye-piece in question was invented by Huyghens for telescopes, with no other view than that of diminishing the spherical aberration by producing the refractions at two glasses instead of one, and of increasing the field of view. It consists of two plano-convex lenses, with their plane sides towards the eye, and placed at a distance apart equal to half the sum of their focal lengths, with a stop or diaphragm placed midway between the lenses. Huyghens was not aware of the value of his eye-piece; it was reserved for Boscovich to point out that he had, by this important arrangement, accidentally corrected a great part of the chromatic aberration. Let fig. 259 represent the Huyghenian eye-piece of a microscope, F F being the field-glass, and E E the eye-glass, and L M N the two extreme rays of each of the three pencils emanating from the centre and ends of the object, of which but for the field-glass, a series of coloured images would be formed from R R to B B; those near R R being

red, those near B B blue, and the intermediate ones green, yellow, and so on, corresponding with the colours of the prismatic spectrum. This order of colours is the reverse of that of the common compound microscope, in which the single object-glass projects the red image beyond the blue.

"The effect just described, of projecting the blue image beyond the red, is purposely produced for reasons presently to be given, and is called over-correcting the object-glass as to colour. It is to be observed also, that the images B B and R R are curved in the wrong direction to be distinctly seen by a convex eye-lens, and this is a further defect of the compound microscope of two lenses. But the field-glass, at the same time that it bends the rays and converges them to foci at B′ B′ and R′ R′, also reverses the curvature of the images as there shown, and gives them the form best adapted for distinct vision by the eye-glass E E. The field-glass has at the same time brought the blue and red images closer together, so that they are adapted to pass uncoloured through the eye-glass. To render this important point more intelligible, let it be supposed that the object-glass had not been over-corrected, that it had been perfectly achromatic; the rays would then have become coloured as soon as they had passed the field-glass: the blue rays, to take the central pencil, for example, would converge at b, and the red rays at r, which is just the reverse of what the eye-lens requires; for as its blue focus is also shorter than its red, it would demand rather that the blue image should be at r, and the red at b. This effect we

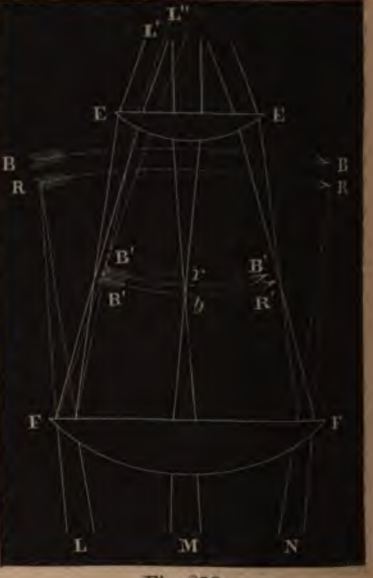

Fig. 259.

have shown to be produced by the over-correction of the object-glass, which protrudes the blue foci B B as much beyond the red foci R R as the sum of the distances between the red and blue foci of the field-lens and eye-lens; so that the separation B R is exactly taken up in passing through those two lenses, and the whole of the colours coincide as to focal distance as soon as the rays have passed the eye-lens. But while they coincide as to distance, they differ in another respect,—the blue images are rendered smaller than the red by the superior refractive power of the field-glass upon the blue rays. In tracing the pencil L, for instance, it will be noticed that, after passing the field-glass, two sets of lines are drawn, one whole and one dotted, the former representing the red, and the latter the blue rays. This is the accidental effect in the Huyghenian eye-piece pointed out by Boscovich. The separation into colours of the field-glass is like the over-correction of the object-glass,—it leads to a subsequent complete correction. For if the differently coloured rays were kept together till they reached the eye-glass, they would then become coloured, and present coloured images to the eye; but fortunately, and most beautifully, the separation effected by the field-glass causes the blue rays to fall so much nearer the centre of the eye-glass, where, owing to the spherical figure, the refractive power is less than at the margin, that that spherical error of the eye-lens constitutes a nearly perfect balance to the chromatic dispersion of the field-lens, and the blue and red rays L″ and L′ emerge sensibly parallel, presenting, in consequence, the perfect definition of a single point to the eye. The same reasoning is true of the intermediate colours and of the other pencils."

Dr. August gives the following method of ascertaining pretty accurately the magnifying power of a compound refracting microscope. An object, of which the size is known, has to be placed before the object-glass; then looking with one eye through the microscope, with the other look at the points of a pair of compasses, held at the distance of distinct vision before it. Having adjusted the compasses to the diameter of the object seen through the microscope, divide this diameter by the known diameter of the object, both being in the same denomination, and the result will be the magnifying power sought.

We subjoin the following comparative micrometrical measures by Dr. Hannover, as a reference table:—

Millimetre.	Paris lines.	Vienna lines.	Rhenish lines.	English inch.
1	0·443296	0·4555550	0·458813	0·0393708
2·255829	1	1·027643	1·035003	0·0888138
2·195149	0·973101	1	1·0071625	0·0864248
2·179538	0·966181	0·992888	1	0·0858101
25·39954	11·25952	11·57076	11·65364	1

The wonderful tracing on glass executed by M. Nobert, of Barth, in Prussia, deserves attention. The plan adopted by him is to trace on glass ten separate bands at equal distances from each other, each band being composed of parallel lines of some fraction of a Prussian inch apart; in some they are $\frac{1}{1000}$th, and in others only $\frac{1}{4000}$th of a Prussian inch separated. The distance of these parallel lines forms part of a geometric series:—

0·001000 lines.	0·000463 lines.
0·000857 „	0·000397 „
0·000735 „	0·000340 „
0·000630 „	0·000292 „
0·000540 „	0·000225 „

To see these lines at all, it is requisite to use a microscope with a magnifying power of 100 diameters; the bands containing the fewest number of lines will then be visible. To distinguish the finer lines, it will be necessary to use a magnifying power of 300, and then the lines, which are only $\frac{1}{4700}$th of an inch (Prussian) apart, will be seen perfectly traced. Of all the tests yet found for object-glasses of high power, these would seem the most valuable. These tracings have tended to confirm the undulatory theory of light, the different colours of the spectrum being exhibited in the ruled spaces according to the separation of the lines; and in those cases where the distances between the lines are smaller than the length of the violet-coloured waves, no colour is perceived; and it is stated, that if inequalities amounting to ·000002 line occur in some of the systems, stripes of another colour would appear in them.

A Solar Microscope is for transparent objects, and can only be used with the hydro-oxygen light, or when the sun shines strongly, the rays from which, being received on a plane

mirror, are reflected through a lens called a condenser, in a shutter or through a tube, into a darkened room; and nearly in the focus of these condensed rays another lens is placed, so as to obtain a large amount of light, but at the same time avoiding the heat rays, which would otherwise fall upon the object placed within the burning focus. The object-glass is adjusted to bring the object exactly in its focus, thence the rays cross and diverge to a white screen on which the image is seen: the magnifying power depends on the distance of the screen from the window. This microscope is employed that several persons may at the same time see the same object. It has also lately been used for throwing the magnified images of microscopic objects upon prepared photographic surfaces of a very large size, and with surprising effect. The hydro-oxygen microscope is a modification of the solar; a jet of hydrogen and oxygen gas being ignited, is allowed to play on a small cylinder of lime placed in the interior of the instrument.

The luminous effects produced by exposing lime to a jet of the ignited gases is familiar to every one. This brilliant light was first adapted to the illumination of the microscope by Charles Woodward, Esq., F.R.S., who succeeded in exhibiting transparent objects by its aid, and thus rendering this valuable instrument of philosophical research available at all times and for many purposes; the beauty of the *Dissolving Views* may be especially instanced.

The Stand, Lantern, and Caoutchouc Gas-holders.—In fig. 264, *a* represents the mahogany lantern and its sheet-iron chimney; *b* the mahogany base, on which the lantern can slide in a dove-tail groove, so as to permit the movement of the lenses to or from the lime-light. This base is hollow and pierced, to admit the ascent of a current of air between the first condensing lens and the lime-light, which keeps the former cool, and carries off the volatilized particles of lime, which, if allowed to settle on the glasses, would impair their transparency. *c* is a triangular frame supporting the base *b*. A shelf is seen in front attached to the frame *c* by a pair of hinges, which permits it when not in use to fold up in front of the base *b*; and when wanted, to hold the objects for exhibition, powers, &c. *d*, *d'* *e*, *e'*, *f*, *f* are the three pairs of legs of a tripod support for the whole.

The arrangement for the supply of gases possesses many advantages: the principal one is, that by an elongation of the flexible tubes g h, the gas-holders may be placed in a separate

Fig. 260.—The Hydro-oxygen Microscope.

apartment, so as completely to obviate any objections to the exhibition of the gas microscope in family circles. The two gases are kept perfectly isolated until brought together at the

point of the blowpipe for combustion. They are introduced (by means hereafter described) into separate bags, provided with pressure-boards and weights; the name of each gas being distinctly branded on its proper pressure-board *i*, *k*, to avoid the possibility of mistake. Each bag is connected with the blowpipe by a separate flexible tube *g*, *h*; these tubes are attached by union-joints and stop-cocks to the gas-bags *m* and *n*, which are constructed of india-rubber cloth, perfectly air-tight.

Fig. 261 affords a skeleton view of the parts connected with the gas blowpipe. *a* is a side view of a portion of the front of the lantern, supporting the tube that holds the condensing lens; *b* is the mahogany base before mentioned, on which the lantern slides, and through which the blowpipe and lime-holder *h*, bearing the lime-cylinder *i*, are firmly inserted. A square piece of brass *x* is fixed on the bottom of the base *b* by three screws. *c*, *d* are two hollow projecting cylinders with exterior screws cut upon them, the threads of which are concealed in the figure by the union-joints that connect them with the flexible tubes which convey the gases (oxygen and hydrogen) from their respective bags (fig. 260, *i*, *k*). Their passage through the solid piece of brass *x* in the figure before us, is regulated by two stop-cocks, the handles of which are not shown in this figure, but may be seen at *l* and *k*, fig. 261, through which they are allowed to enter the blowpipe *e* and combine within it, in given quantities, so as to produce the most brilliant effect when finally propelled and ignited at the platinum nozzle *f*. A spring slit in the outer sliding tube of the blowpipe at *e* permits the nozzle *f* to be elevated or depressed without

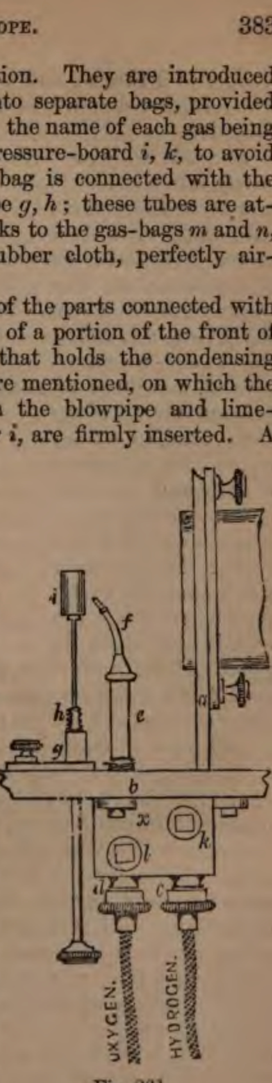

Fig. 261.

danger of leakage; and a universal joint at its base allows it to be further directed with ease and efficiency in any lateral direction.

Fig. 262 exhibits the manner in which the gases enter separately into the blowpipe. A is a piece of brass cast solid, and pierced so as to admit the passage of the two gases. Both cocks are now shown shut. The oxygen gas enters by the pipe B, and when the stop-cock is opened, continues its passage directly along the central tube from o′, to the extremity o″, to which the little chamber nozzle of platinum is attached by a screw. The hydrogen gas is admitted by the pipe C, and when the cock is opened for its passage, finds its further way into the outer chamber H surrounding the oxygen passage o′, and then enters the six small pipes seen only in section; and so continues to the extremity H″, where it is emitted, and combines with the central stream of oxygen gas in the minute chamber provided for that purpose in the interior of the platinum nozzle. The mixed gases then pass on in intimate union, and out through the orifice of the blowpipe nozzle, where they are combined and directed on the lime-cylinder for the purpose of illumination. As the two gases are never mixed in any greater quantity than is contained in the interior of this nozzle, no greater amount of explosion can at any time take place than would be caused by the trifle contained in the "platinum chamber;" a space scarcely worthy of the name (being not larger than a pin's head), were it not that it serves a purpose of safety and of signal, important to the operator and the apparatus. Whenever the cocks are shut so as to cut off the pressure and supply of the gases, the flame naturally retires within the nozzle, and ignites the little

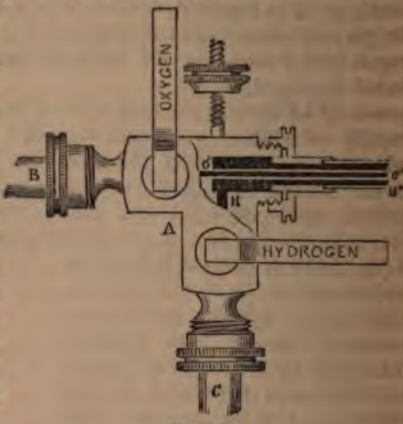

Fig. 262.

explosive mixture which it contains, producing a distinct snapping noise, something like that occasioned by the shutting of a penknife, and indicating the quiet termination of combustion, explosion, and danger of any kind.

Attention must be paid to the position of the blowpipe nozzle so as to attain the most favourable distance and direction for playing upon the lime. This can easily be ascertained and regulated by means of the universal joint. It must be recollected during these trials, that the lime-cylinder is a substance possessed of very slight cohesion; and that it is liable to be rapidly volatilized or carried off by the action of the blowpipe wherever any one portion of the surface is continuously exposed to the intense heat generated at the point of the flame. To prevent this, you must turn the lime-holder every three or four minutes by the milled head at the bottom of the spindle *h* (fig. 261) so as to expose a new surface to the action of the hydro-oxygen jet. This is a troublesome duty, but it must be carefully executed, otherwise the surface of the lime-cylinder *a* would be worn into a hole similar to that represented at *b* (fig. 263), the concavity of which would throw back the inflamed gases against the interior condensing lens *c*, and thereby most probably crack it into a thousand pieces. Magnesia or quartz may be substituted for the lime with advantage.

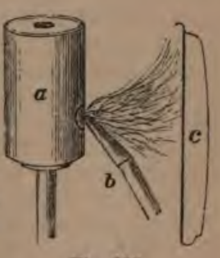

Fig. 263.

The tube attached to the front of the box is shown in fig. 264. *g* is the tube which supports or holds in its prolongation those which carry the objects and magnifying powers. It is firmly screwed into the larger tube *f* by the single-milled rim adjoining, which gives the operator the means of turning the entire of the tubes extending from *g* to *p*, with all the powers and objects that may be contained in them, completely round, either from right to left,

Fig. 264.

or from left to right. The tube *h* is the object-holder. It carries within it a spring tube, which by means of four pins, two of which are shown at *l*, *m*, can be easily pushed inwards towards *g*, so as to open a space for the introduction of the slider containing the objects. On inserting the slider and removing your hand from these pins, the action of the spiral spring will instantly cause the return of the inner tube, so as to close up the vacant space and hold the slider firmly in its place. The objects are brought into the proper focus by a revolving movement of the large milled head *i*, which turns a pinion that acts on a rack in the interior of *h*, and thereby causes it to advance or retreat within *g*, until the slider is adjusted to the exact distance requisite to throw a perfect image on the disc. The portion of the tube in advance, marked *n*, is the *power-holder*, which receives the three magnifying glasses (or *powers*, as they are technically termed) used in this microscope. Only one is used at a time. That shown in its place, marked *p*, is the lowest power of the three, and the most suitable for a learner to commence with. It magnifies about 10,000 times, superficial measurement.

To make and collect the Gases.—The first step towards the use of the microscope is the preparation of the oxygen and hydrogen gases. This is a very simple operation, and may safely be entrusted to any servant of ordinary intelligence after one practical lesson.

In fig. 265, *a* is a cast-iron retort, into which is screwed, air-tight, a piece of gun-barrel tube *b*, with a screw for a union joint at the other end. Pour into this tube as much black oxide of manganese in coarse powder as will fill the body *a*; then place the retort in a good kitchen or parlour fire, in the position shown in fig. 266. The best fuel for the purpose is coke intermixed with charcoal; but any clear-burning fire in any common fireplace will answer the purpose; the heat may be increased by using a common pair of bellows, or the blower *d*.

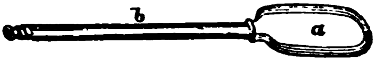

Fig. 265.

After waiting for a few minutes to allow the atmospheric air and moisture to escape, connect by means of the union-screw *a* the end of the iron tube which forms the neck of the retort to the glass bottle *b*, which is arranged for cooling the

gas in its passage, which otherwise might injure the india-rubber cloth bag, by the degree of softness the heat would occasion. It is three-fourths filled with water. The wide

Fig. 266.

mouth is closely fitted with a brass cap cemented upon it, through which pass two flexible metallic tubes; one of these (before mentioned) conducts the oxygen gas from the retort, and opens beneath the water within a quarter of an inch of the bottom. From this orifice the gas issues freely in separate bubbles, to be deprived of its heat as it ascends through the water, which will further retain any condensible impurities that may happen to be volatilized in the process.

When the bag is full, shut the stopcock, and if more gas be required, instantly undo the connexion with the conducting pipe *c*, and transfer the supply to another bag. When the charge in the retort has given forth all its oxygen, it should be taken from the fire, and, having first undone the union-joint at *a*, and removed the flexible pipe that connected it with the bottle, the residual oxide of manganese should be thrown out, whilst still red-hot, by turning the retort with its mouth downwards, and shaking it briskly in a pair of calliper-tongs. If left to cool, the oxide will cake together and become difficult to extricate.

As possibly some of our readers may not be fully acquainted with the properties of oxygen gas, it may be as well to mention, for the removal of any doubts or fears they may entertain, that there is not the slightest danger attending any part of the above process for its production. The gas is not in the least

combustible or explosive, either separately or mixed, whether with common air or with any of the gaseous adulterations which are known to occur either by accident or design. Finally, the raw material (the black oxide of manganese) is perfectly harmless; and we have heard of no inconvenience attending the operations of pounding, sifting, and handling it. The residual brown oxide obtained when the retort is emptied is also similarly inert.

Fig. 267 exhibits the arrangement for the preparation of hydrogen gas. *a* is a lead or thin glass bottle, with two pipes made of glass firmly fixed through a brass cup which screws into its mouth. This bottle is filled to about one-third with zinc cuttings. The upright pipe *b* ends in a funnel, to allow of one part sulphuric acid and six parts of water being poured

Fig. 267.

into the bottle upon the zinc. The bent one permits the passage of the generated hydrogen gas, and is provided with a union-joint at *c*, to connect it with the glass bottle *d*, containing water for its purification.

It is necessary to allow all the common air included in the generator and purifier to escape in the first instance, even though some hydrogen be lost at the same time, previous to receiving the gas in the bag H Y, otherwise an explosive mixture would be formed in it. A little experience will soon enable the experimenter to form a correct opinion whether all the atmospheric air has been expelled, and whether the hydrogen is passing purely through the water in the purifier. When it is generated at a proper rate, three or four bubbles will be seen to issue smartly from the pipe *c* every second, and then discharged through the water with a very peculiar sound, not loud but distinct, and unlike any other; arising perhaps

from their great levity, being 11,000 times lighter than the water through which they pass, and the consequent rapidity with which they rise to the surface.

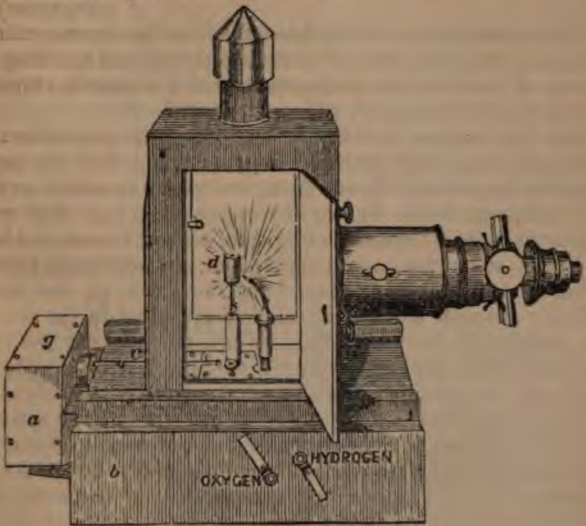

Fig. 268.—Interior of Lantern.

Take care not to approach the purifier or the open union-joint with a lighted candle, while the mixture of air and gas is passing off, for being together lighter than the atmosphere, it would ascend, and, if it come in contact with the flame, readily explode, and possibly crack the glass bottle; thereby, in all probability, spilling the water and thus deranging and delaying the process, as well as wasting the hydrogen gas in progress of generation, though no greater mischief would be likely to happen. In most cases the preparation of hydrogen gas may be dispensed with, as the ordinary carburetted hydrogen gas supplied by the gas companies to the house will answer the purpose very well.

Having effectually guarded against leakage by ascertaining the completeness of all the union-joints, the next step is to complete the blowpipe arrangement by putting a lime-cylinder *d* on the lime-holder; fig. 268 shows the arrangement of the

interior of the lantern, with e. g. a brass box attached, containing a small piece of clock-work motion to keep the lime-cylinder revolving. This only need be added when cost is no object.

When you have perfectly fixed the lime by turning on the hydrogen-jet alone, you may introduce the oxygen gas into the centre of the flame by gently opening the stopcock. Should you do this suddenly, you will extinguish the flame altogether. When the oxygen is skilfully and patiently admitted, the compound flame will produce a brilliant glow on the lime-cylinder altogether different from, and vastly superior to, the best effect produced by the hydrogen-jet. You may now attain the highest intensity of light by holding the oxygen and hydrogen stopcocks one in each hand, adjusting nicely the influx of both gases, and watching the effect on the lime-cylinder through a piece of coloured eye-glass in the side of the lantern, if the naked light be too powerful for the eye, until by gradually increasing or diminishing the supply of each, you arrive experimentally at the proper proportions of both. An excess of hydrogen will be indicated by the appearance of a reddish flame surrounding, and of course obscuring, the glow of white light that radiates from the cylinder. Additional oxygen will remove the redness; but an excess of this gas will diminish the white light, and if the proportion be increased, will at last extinguish it altogether.

The first point in the management of the lantern is to obtain a uniform disc of light on the whitewashed wall, or on a white linen or calico screen hung perpendicularly against it for the purpose. When you find that the lime-cylinder *d* is giving out an intense steady light, place the low magnifying power on the end of the tube, shut the door of the lantern, and exclude every other light from the room except what passes through the microscope to the wall. When you turn your eyes towards the disc produced there, you will perhaps be much disappointed at beholding its centre only lit up, and darkness radiating towards the circumference; or, *vice versâ*, the centre very dull, and a scattered illumination towards the edge of the circle. These defects are, however, easily removed; both are occasioned merely by the want of adjustment of the focal distance between the lime-light and the first condensing lens; and both may be obviated by sliding the body of the lantern which car-

ries the lens (while the light stands fast) to and fro in the groove at the top of the base-board, until the proper focal position be attained, when the disc of light will be uniform throughout.

This being accomplished, you may proceed to put the apparatus to work—to illuminate and magnify the objects prepared for the purpose. These are generally set between two pieces of glass in a long thin mahogany frame, and usually consist of the wings of flies, moths, and butterflies, the wings and wing-cases of beetles, bugs, locusts, and grasshoppers, the feathers of birds, the cuttings of wood, some of which are extremely beautiful, the scales of fishes, the petals and leaves of plants, the branches of mosses, &c. The family of ferns furnish a numerous and very interesting class of objects, a specimen of

Fig. 269.

which is shown in fig. 269, and is well seen with a low magnifying power.

A large class of objects may be obtained amongst the temporary inhabitants of the waters, the larvæ of various libellulæ, and gnats. The exuviæ or cast-off skins of spiders, caterpillars, and other insects that undergo metamorphoses, also form interesting objects for examination. The various dissections of the tracheæ and bronchia of caterpillars present very curious and beautiful objects.

Fig. 270 represents the perfect form of a very interesting aquatic insect, the Nepa, or water-scorpion.

Fig. 270.

The decomposition of water by chemical action presents a very curious appearance under the gas microscope, fig. 271. This exhibition is effected by the adaptation of a glass trough to the microscope (to be introduced horizontally in the manner

of a slider), containing dilute sulphuric acid (similar to that employed in the preparation of hydrogen gas), and dropping into it a few pieces of fresh broken zinc. Decomposition of the water instantly commences. Its oxygen gas combines unperceived with the zinc, which then dissolves gradually in the sulphuric acid; while the hydrogen gas set free at the same instant rapidly rises in bubbles through the liquid and escapes at the surface. These bubbles, magnified, present a most extraordinary appearance, forming a series of whitish luminous globules descending in the fluid (for every thing appears reversed in the microscopic exhibitions) from an opake surface, and swelling enormously as they struggle to the surface under the expansive powers of heat, combination, and lessening pressure.

A beautiful series of objects may be shown by the crystal-

Fig. 271.

lization of various salts from chemical solution; or we may turn to the vast field of animalcule life presented in a single drop of standing water, for subjects of wonder and admiration. If we take a little sour paste diluted with water, and place a drop of the mixture on a single glass slider, and introduce it in the same way into the microscope, we shall find an object of singular interest presented to our view on the illuminated disc: tens of thousands of living animalcules, resembling eels, are seen struggling and twining in masses so densely congregated, that it appears as if they alone constituted the paste. Their numbers defy all attempts at calculation while they are free to move; but as the water evaporates under the influence of the transmitted heat, these agitated masses are seen to grow gradually more and more quiescent, until at last they lie motionless, rigid, and dead. Then some estimate may be formed of their numbers, and it will probably be found that the drop contained millions. The vast field of observation and inquiry which such a sight opens to the zoologist and naturalist is too obvious to require comment.

It will be necessary to give some information respecting the discs employed by exhibitors. They are of different sorts; fixed or rolling, opake or semi-transparent. The best is the fixed opake, for then no light is lost by passing through; and all that is necessary to form one, is to whiten the side of a room like a ceiling. If the room be papered with a raised flock pattern, it will be necessary, prior to colouring, to rub it down with pumice-stone, so as to reduce the inequalities. The white paint used must be a distemper, not an oil-colour, as there must be no gloss apparent. If a circle be struck, and all outside it blackened, the effect in many situations will be rather ornamental than otherwise. Mechanics' institutions, school-rooms, and scientific lecture rooms, have generally white-washed walls, and no expense need be incurred in such cases, as nothing can answer better; nor is it necessary to blacken the circumference of a disc. Indeed, where the apartment is small, it is a decided disadvantage; for should the room be fourteen feet long and only eight feet high, a disc circumscribed by a black exterior would only show an object eight feet long; but should the object be a long narrow one, it would be desirable to show it from one end of the wall to the other.

The magic lantern somewhat resembles the gas microscope

in appearance, and may be made so in arrangement, although a cheaper kind is formed of tin, having a chimney to carry off the smoke from a common oil-lamp. At the back is placed a concave reflector C (fig. 272), which reflects the light to the plano-convex lens M. From this it proceeds to a transparent painting on glass S, fixed in a slide, so as to be moveable: it is placed in an inverted position. From this slide the light passes to another lens L, which is convex, and fixed in a sliding tube, to enable it to be brought to the requisite distance or focus on a screen in a dark room; a large erect image of the design on the glass is seen painted on the opposite wall.

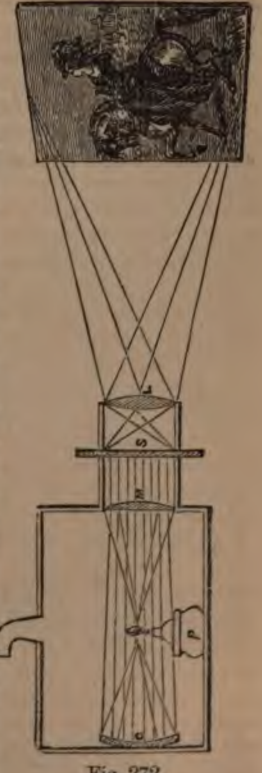

Fig. 272.

No public exhibition ever excited more sensation than that of the Phantasmagoria; by the representation of terrific figures, which seem to approach the audience from an amazing distance, and then recede again, rise to the ceiling, and then descend to the floor. This optical illusion is nothing more than a magic lantern, having all the glass opake, excepting the figure, which is painted in transparent colours. Thus no light can fall upon the screen, except what passes through the figure itself. The screen being placed in front of the audience, while the operator is on the opposite side, with the lantern fixed on a table that can be silently moved backward and forward, the figures appear to advance and retire. The size of the images increase when the lantern is carried back, because the rays come in the form of a cone; and as no part of the screen can be seen, the figure appears to be formed in the air, and to move further off when it becomes smaller, and to approach as it increases in size.

The beautiful optical representations called dissolving views are effected by having two magic lanterns at an equal distance, both of the same focus; and while the view of one is being withdrawn, the other is emerging forth, realizing almost the imaginary tales of the powers of magic and of fairies.

The Camera Lucida.

The Camera Lucida was invented by Dr. Wollaston in 1807, and consists of a four-sided prism of glass set in a brass frame

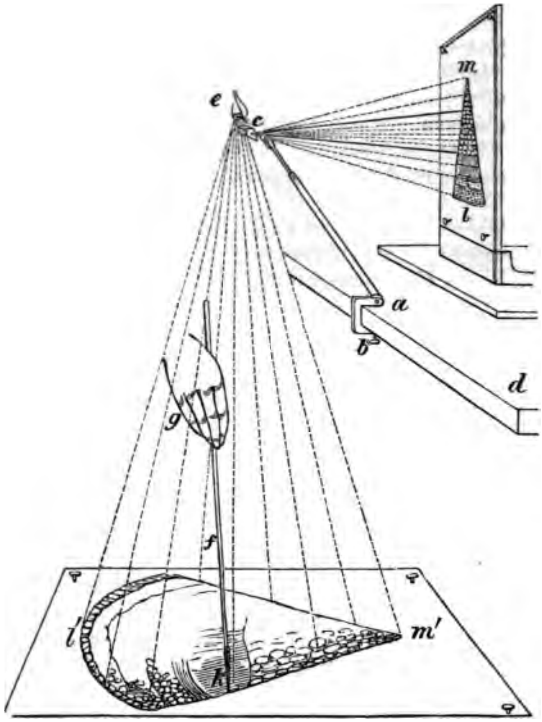

Fig. 273.—The Camera Lucida.

or case. It is screwed on to a table, being supported about six

or eight inches from the surface by a sliding tube to suit the sight or position of the object. The rays from the object passing through the glass, are reflected from the lower and back surface of the prism to the eye; and in the same direction as the last ray, the table or paper placed to receive it is visible, and the image therefore faintly delineated; and as the point of the pencil is also visible, the image may be traced on the paper. A piece of brass having a small hole is fixed on the top, and used as a sight-hole to keep the eye to one point.

Besides the valuable assistance rendered to the draughtsman by this instrument, its application to drawing objects from the microscope, or increasing the size of an object already drawn, for the purpose of showing an enlarged view or diagram for the lecture-room, may be effected in the following manner. Place the tracing *m l* (fig. 273), made from the microscope by the camera as an object for another camera *c*; this being fastened to the table *d* by the screw *a b*, and the object *m l* set up in front of it, an accurate outline on a larger scale *m′ l′* can be made on the floor or table placed four feet below the upright picture, this being the utmost limit of space between *c* and *k* to allow of the pencil being used with advantage. The pencil *k*, with a long handle *f*, being held by the hand *g*, the artist standing either in front or on one side of the camera, and applying his eye as at *e*, may proceed to make an accurate drawing of the object.

To the microscope it is a valuable addition, and is employed to make drawings of the wonders revealed, without having to move the eye and trust to the fidelity of the memory and accuracy of the pencil.

Photography.

Time was when it would have gone hard with any one who showed pictures of men and scenes that neither pencil, brush, nor hand had touched; and if, in defence, it had been asserted that the sun itself had traced them, the tortures of the rack would have been had in requisition to force the inventor to confess himself a wizard, and to tell his terms of compact with the devil; even in our own time, though we have passed from demonism, there is a lingering tendency to set down those who go exploring beyond the bounds of knowledge as madmen. Almost any one can find instances; but we are

content to mention one which has connexion with our present subject. At the close of a lecture by M. Dumas, the well-known French chemist, a lady came to him in the lecture-room; she had a question of great moment to ask him. "Did he think it possible that the pictures seen in a camera could be caught and made permanent?"—she was anxious to know what he, a man of science, thought on the subject. Her husband had been seized by the idea that he could fix these pictures; day and night he was haunted by the thought; she feared he might be mad. But if a philosopher like M. Dumas thought there was any probability in the notion, it would give her the belief that her husband might still be in his senses. Dumas assured her that, though he saw no way to fix the pictures, enough was known to prevent him from saying it was impossible, and to make it matter worthy of inquiry. The lady's husband was Daguerre the painter; and some ten years after this conversation with Dumas, he had solved his problem, and taught the world the art which bears his name.

Mr. Wedgwood, the celebrated porcelain manufacturer, published the first account in 1802 of a method of 'Copying Paintings upon Glass, and of making Profiles by the agency of Light upon Nitrate of Silver.' He was assisted by Sir Humphry Davy, but both failed to fix the images; and the process was abandoned, until the successful experiments of Niepce and Daguerre with the prepared surfaces of bitumen, resin, and essential oil of lavender, induced them to try other substances; and eventually they were rewarded by the discovery of the action of light upon the iodide of silver, and the subsequent fixing of the image upon a silver plate. Mr. Fox Talbot also, about the same time, hit upon a method of fixing the images upon paper prepared with a solution of nitrate of silver; this he effected with common salt, and afterwards the same salt as Daguerre employed with his silver plate, viz. hyposulphite of soda.

The year 1839 gave birth to this, and also the electrotype process; two of the most extraordinary discoveries of human ingenuity, which, from the similarity of their results, may be called sister arts, both acting under two of the most mysterious agents of Nature's wonderful works—the one under the influence of light, the other under that of electricity: in the first, light draws; in the latter, electricity models. With the

original process it was considered impossible to apply it to portraiture; for with iodine alone and the long foci of lenses employed at first, no picture could be taken in less time than from fifteen to thirty minutes. As the correctness of a portrait produced by this art depends upon perfect immobility during the whole of the sitting, the bare idea of such an application of photography was thought altogether absurd.

It was, however, soon found, that by constructing object-glasses with shorter foci, the operation could be reduced nearly in proportion to the reduction of the length of the focus; so that, by making use of an object-glass of three inches focus instead of twelve, the operation is shortened by four times, and thus portraits are able to be taken.

Within the last two years more wonderful results have been obtained by using prepared surfaces of collodion, or gun-cotton and the white of egg; so that at the present time a degree of perfection is obtained, that has elevated the discovery into one of the most elegant and profitable scientific pursuits.

It is not quite true to assert that these pictures are produced simply by *light*, they are the effects of the boundless power of natural chemistry; for in proof that it is not light in itself which executes these works, it may be observed, that if a piece of paper be rendered sensitive and placed under a glass globe of the darkest possible blue through which the sun's rays can scarcely permeate, the paper loses in a few seconds all its sensibility. On the other hand, if the same paper be placed under a similar globe, but coloured of the faintest yellow, its capability of receiving an image thereafter is uninjured. It is evident, therefore, that it is not *light alone* which produces these results—it is some agency dwelling in light in the same manner as electricity dwells in the atmosphere, and produces consequences irrespective thereof. This agency or quality of light, which philosophers know nothing of, they have termed the *actinic power of light*.

We now proceed to describe, as briefly as possible, some few of the processes employed in the science of photography.

Positive and negative pictures.—If we take a piece of paper and wash it over with a solution of nitrate of silver, and allow it to dry in the dark, no change takes place in its appearance. The instant, however, that we expose it to the light, it darkens all over; but if, instead of exposing it wholly, a portion of

the paper be covered, say with the leaf of a plant or a piece of lace, it is obvious that those parts which are shielded from the light will remain unchanged, whilst those which are exposed to it will become black. We shall thus have delineated on the paper the fac-simile of the leaf or lace which will appear white on a black ground. This is what is technically termed a *negative picture*. Having got this negative, it is clear that if we make use of it in the same manner as we did the leaf or lace, by placing it on another piece of prepared paper, and then expose it to the light (the negative having first gone through a process which prevents all further action of light upon it), we shall get the reverse of the negative, and this is technically termed a *positive picture*. By means of the camera obscura (fig. 277) negative pictures are delineated on sheets of glass or waxed paper, and then positives are obtained therefrom. The process of taking the positive from the negative is termed *printing*, and there is no limit to the number of positives which may be taken from one negative.

Talbotype or Calotype.—It was found that the simple wash of nitrate of silver did not render the paper sufficiently sensitive to be acted upon in the camera obscura; Mr. Fox Talbot, however, discovered the method whereby this might be effected with extreme rapidity. The surface of the paper is covered evenly with iodide of silver, and when dry, a solution of nitrate of silver holding a small quantity of acetic and gallic acid is applied to the same side of the paper which has been iodized; the paper then becomes extremely sensitive to the action of light. On being taken from the camera in which it has been exposed for a few minutes, scarcely any trace of an image is to be seen—the picture is made to appear, or as it is termed *to develope*, by again washing it with the gallo-nitrate solution. After this it is plunged into water and well-washed, and then *fixed* or rendered indelible by immersing it in a solution of hyposulphite of soda.

Waxed-paper process.—This is perhaps the method which photographers chiefly employ, because in printing from negatives thus produced, the transparency of the paper readily allows the light to pass through it, and hence the positive paper beneath it is more sharply and brilliantly darkened. It also possesses the great desideratum of allowing the paper to be kept longer without injury after being made sensitive. The

paper is in the first instance saturated with white wax, and then held before the fire or heated between folds of blotting-paper, by means of a hot smoothing iron, until all the excess of wax is carried off, when it assumes a vellum-like appearance. In this state the paper is *iodized* and rendered sensitive by a similar process to that pursued in the calotype—it is then ready for the camera.

The Collodion process.—If common cotton wool or flax be steeped in a mixture of nitric and sulphuric acids, and afterwards washed and dried, it becomes very explosive, and has received in consequence the name of gun-cotton. If a portion of the cotton or flax thus prepared be placed in sulphuric ether, it readily dissolves, forming a thick volatile mucilage, which is called collodion. The way in which it is employed in photography is as follows. A small quantity of the iodide of potassium having been added to the collodion, it is poured over a sheet of plate glass; the ether evaporates, leaving a thin film of collodion (holding iodide of potassium) on the glass. The glass is next plunged into a solution of nitrate of silver, and in a few seconds an iodide of silver is formed upon the collodion; it is now highly susceptible to the action of light. On placing it in the camera in its wet state, the collodion side being nearest to the lens, an image is very quickly formed thereon; when taken from the camera, a solution of proto-sulphate of iron is poured upon it; instantly the image, which was before invisible, is developed. It is then washed, and the picture is fixed by passing over it a solution of cyanide of potassium or of hyposulphite of soda. As the film of collodion is extremely delicate and easily abraded, it must be protected by a coating of some transparent varnish.

The Albumen process.—This process, which was practised before that by means of collodion, is similar thereto. The sheet of glass is coated with a film of albumen (white of egg) which has been iodized as the collodion was, and the sensitive quality is given thereto in the same manner. This process produces extremely beautiful results, and the aërial effect of distance is perhaps better obtained by it than by any other. Mr. Fox Talbot has discovered a method of operating with albumen which, from its rapidity of action, he has termed "the instantaneous process." By this method an image was obtained of a printed handbill made to revolve rapidly on a

wheel and lighted up during a fraction of a second by a powerful electrical discharge.

Photographic engraving.—Photographic engravings may be executed on steel plates. The steel plate is coated with a solution of gelatine, and afterwards with one of bichromate of potash which possesses photographic qualities. When these solutions have dried upon the plate, it is ready to receive a photographic image. Let a piece of black lace or the leaf of a plant be applied closely to the surface of the plate in a photographic printing frame, and then exposed to the action of light, a yellow image of the object will be found impressed upon a brown ground. The plate is then immersed in cold water, which dissolves the film of bichromate and gelatine from all the parts which have not been exposed to the sun's rays, thus leaving the photographic image quite visible. This image is then etched into the plate by pouring upon it a strong solution of bichloride of platinum. With other objects a negative photograph may be taken by means of the camera, a positive is then produced on glass or waxed paper, and this is then placed in contact with the plate in the same way as the leaf or lace above described.

Photo-lithography.—The application of photography to the lithographic stone is quite a recent discovery. The stone being prepared in the usual way, it is imbued with a weak solution of sesquioxide of iron; it is then placed in the camera in a moist but not a wet state; and after being exposed a sufficient time, the image appears of a brownish colour: the picture is still more developed and fixed by means of a solution of carbonate of ammonia. The stone is then floated with water to wash away the soluble salts. This impression can be made to print by etching the stone with diluted oxalic acid, and then proceeding with the usual lithographic process. By means of glass or wax-paper negative photographic positives may be printed from the stone. The stone is covered with asphaltum dissolved in etherial oil; the negative is then brought in close contact with it and exposed to the light. The resinous coating loses its coherence in the parts corresponding to the lights of the negative. Upon blackening the stone with lithographic ink, the ink adheres to the stone in the denuded parts only. The surface is then treated with an acid which decomposes the soap, spreading a fatty layer over

the entire surface of the stone. The stone is then washed with alcohol, which breaks up the resinous coating, removing it and the fatty layer thereon, but the previously denuded portions remain intact. The stone is then etched and printed in the usual way.

Photo-galvanographic process.—A plate of glass is thoroughly well cleaned, a quantity of glue is dissolved, and three different solutions made, which we will number respectively—1, Nitrate of silver; 2, Iodide of potassium; 3, Bichromate of potash: to each of these some of the glue is added; the largest portion to the solution No. 3, then No. 1 is added to No. 3, and both solutions mixed together; the previous yellow solution becomes a fine red, from the formation of the chromate of silver, which is held in suspension. Solution No. 2 is now added to the mixture of 1 and 3; the mixture loses colour slightly, but it still remains a fine red colour. This mixture, which involves some very curious chemical phenomena, is poured over a glass plate, and by careful manipulation a perfectly uniform film of a red colour is produced; this part of the process is performed in a room illuminated with yellow light, and maintained at a tolerably high temperature. When solidified, the plate is fit for use; a photographic view, a portrait, or an ordinary engraving is placed upon the gelatine tablet, this arrangement is fixed in a frame, and duly exposed to the solar rays. In the course of a short time all the exposed parts blacken to a brown, and the lines beneath the superposed photograph or print are darkened or preserved from change, as the case may be, until a copy of the original is obtained inverted. All the dark lines, or portions of a print or of a photograph, remain unchanged. All the light lines or portions darken, the degree of darkening being determined by the relative transparency of the several parts.

The glass plate is, at the proper time, taken from the copying frame and plunged into water. The picture is now perceived to be gradually developing itself with extraordinary beauty. All the unchanged portions of the plate are rapidly dissolved off, and subsequently the picture is produced, not merely by differences in the colour of the surface, but by variations in the thickness, corresponding with the amount of actinic action which has taken place during the exposure of the plate.

When the proper effect is obtained the process is stopped,

the surface dried off with blotting-paper, and the plate preserved for the subsequent manipulation. It will be understood that the chromic acid of the bichromate of potash, at the moment of separation from that salt, when the actinic change is effected, combines with the gelatine and renders it insoluble. Hence in the picture we have several thicknesses of gelatine films, representing the high lights, the middle tones, and the deep shadows with all the beautiful gradations between these which are obtained in a highly finished collodion photograph.

This constitutes the photographic part of the process, the remainder of the manipulations being the preparation for, and carrying out of, the electro-chemical preparation of the copper plate from which the photogalvanographs are to be printed. The photograph being placed on a firm bed, a sheet of elastic gutta percha is spread over it, and it is subjected to some pressure; this receives a very perfect impression of the picture, all the lines, however delicate, being faithfully preserved: when this has hardened, its surface is prepared so as to render it conducting, and is then subjected to the ordinary electrotype process, being placed in a cell filled with sulphate of copper, and connected with a plate of zinc, in a porous cell excited with dilute sulphuric acid. Thus a sheet of fine copper is precipitated upon the mould, and a plate, the reverse of the mould, is obtained. It will be evident that we are thus enabled to obtain either a raised image or an engraved impression. At present, the processes for printing the plates in relief are not quite perfect, but the prints taken from the engraved plates are in a very perfect condition; in these, for the first time, we see all the minute details represented, with the half-tones as finely given as the high lights or the shadows.

Daguerreotype process.—This process consists in rendering a silvered plate sensitive to the action of light by exposing it to the fumes of iodine. On removing it from the camera, the picture is developed by means of heated mercury, and fixed by plunging it into a weak solution of hyposulphite of soda. Daguerreotypes are all positive pictures.

The polishing of the silver plate, after cleaning with a weak solution of acid and water, is effected by the aid of charcoal powder and a buff, consisting of a piece of wood covered with cotton velvet represented in fig. 274; coating the surface, by

exposing the plate over a glass pan containing iodine for a few minutes, as represented in fig. 275, which is so contrived that

Fig. 274.

it can be slid from the iodine vapour to the next containing bromine. The plate is then placed in a small dark slide (fig. 276), carefully secluded, and exposed in a camera (fig. 277) to the action of light; the camera-box is made of deal or mahogany, about twelve inches or more in

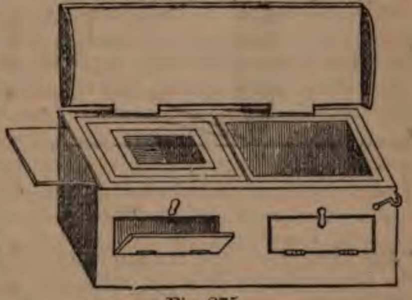

Fig. 275.

Fig. 276.

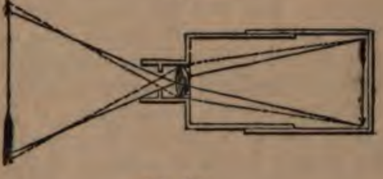

Fig. 277.

length, with a meniscus lens, or a set of achromatic lenses. Here we must direct the student's attention to what has been stated with regard to the action of light as it passes through lenses, as well as to the composition of light, viz. that all the colours which form a ray of white light are not equally refracted by lenses, and consequently cannot meet at the same focus and form a white ray; and not only does this fact explain the colouring of the image, but also the want of sharpness and clearness in those parts of a picture farthest from the centre, or point of focus. The following example will perhaps render the foregoing more easy to be understood.

If L L (fig. 278) be a double-convex lens, and R L, R L parallel rays of white light, composed of the many-coloured rays, each having a different index of refraction, they cannot be refracted to one and the same point—the red rays being the least refrangible to V; the distance V r constitutes the chro-

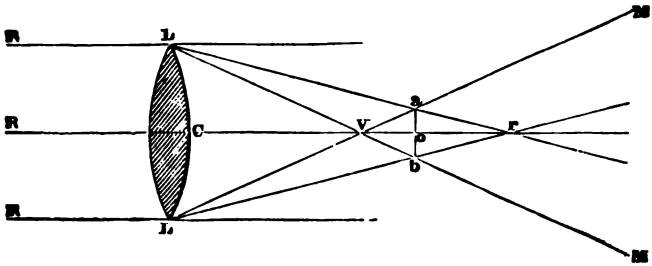

Fig. 278.

matic aberration, and the circle, of which the diameter is a b, the place or point of mean refraction, and is called the circle of least aberration. If the rays of the sun are refracted by means of a lens, and the image received on a screen placed between C and o, so as to cut the cone L a b L, a luminous circle will be formed on the paper, only surrounded by a red border, because it is produced by a section of the cone L a b L, of which the external rays L a, L b are red; if the screen be moved to the other side of o, the luminous circle will be bordered with violet, because it will be a section of the cone M a M b, of which the exterior rays are violet. To avoid the influence of spherical aberration, and to render the phenomena of coloration more evident, let an opake disc be placed over the central portion of the lens, so as to allow those rays only to pass which are at the edge of the glass: a violet image of the sun will be seen at V; red at r; and, finally, images of all the colours of the spectrum in the intermediate space; consequently the general image will not only be diffused, but clothed with prismatic colours. Opticians have bestowed much care in the correction of this and other imperfections; the result is that lenses are now constructed nearly free from such defects.

A good lens being obtained, it is placed in a tube at one end of a box, with the necessary adjustments, and the instrument

is complete. The most simply constructed box is that shown in fig. 277, where the lens is placed in one box which slides into another, so that by moving the box backward or forward, we may secure the correct adjustment of the focus, which is determined by the distinctness of the image seen upon a plate of ground glass placed at the extreme end of the outer box. The ground glass at the end of the outer box should be fixed in a frame which falls into a groove, so as to be easily removed or put in its place. Some frames, as fig. 276, should be made which fit exactly into the space occupied by the ground glass; so that, when a frame is put in its place, and the shutter drawn up, the prepared paper or plate coincides in situation with the place occupied by the ground glass previously. Several of these frames may very easily be made to fit into the box, and each one contain a sensitive tablet.

An exposure of a few seconds in the camera will suffice to impress the image; the plate is then submitted to the vapour of mercury, heated to about 150 or 200 degrees in a box represented in fig. 279, there to remain for several minutes until the picture is developed, which may be seen by examining it from time to time through the piece of yellow glass let into the side of the box; it is then removed, and plunged into a bath of hyposulphite of soda (fig. 280), when the iodine will be seen to leave the surface rapidly; afterwards let it be well washed in clean water to free it from the hyposulphite of soda, placed on a stand (fig. 281), and fixed by pouring a small quantity of the solution of chloride of gold upon the surface; this must be heated by placing a spirit-lamp under the plate until small bubbles quickly arise; the fluid is then thrown away, and the plate dried without delay over the spirit-lamp.

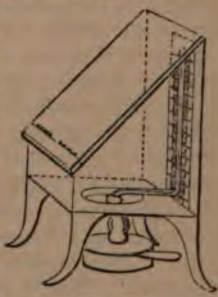

Fig. 279.

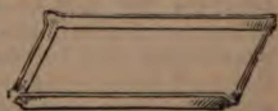

Fig. 280.

We find in the daguerreotype process that those parts of iodized silver plate upon which the light has acted with most power, receive, in the exposure to the vapours of mercury, the

largest quantity of that vapour over their surfaces, and the gradations of light are marked very beautifully by the thickness of these mercurial films. But remarkable enough, the mercurial vapour does not enter into combination with the surface of the plate, unless it has previously been exposed to the influence of light. A plate exposed to the mercury before and after it had been coated with iodine, was not affected in its after operation in the camera by this premature exposure; so that it is absolutely necessary that the mysterious influence of light should be exerted upon the plate before any degree of affinity exists between it and the vapour of mercury with which it is brought in contact.

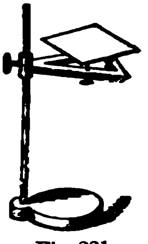
Fig. 281.

Interference of Light.

The phenomena of the interference of rays of light are of the greatest interest theoretically, as throwing much light upon the intimate nature of the ray, and especially demonstrating its close analogy to the lines of undulation or vibration as observed in substantial bodies.

Suppose that two equal systems of circular waves be produced by dropping two pebbles into a still sheet of water, the waves, as they radiate from each centre, will cross one another. But by this crossing the number of waves will be probably diminished instead of doubled. For where the crests of two waves coincide, the height of the waves will be doubled; but where the crest of one coincides with the trough of the other, the water will become level. These are what have been called "lines of double disturbance," and "lines of no disturbance." Where one wave is half an undulation behind the other which it meets, the result will be still water—the annihilation of both waves. The same is observed of the vibrations that produce sound. Let two stretched catgut strings, not in unison, be set vibrating simultaneously. Each gives its own note, but the result of their meeting will be a compound sound, which remits and swells by turns. These alternate dyings away and revivings are termed *beats*. One string vibrates faster than the other; when the direction of two vibrations coincides, an intense note is produced; when they oppose each other, the result is neutralization or silence.

If two pencils of red or yellow light be admitted into a darkened room through two pinholes near each other in the shutter, and the light be caught upon a screen just beyond the point where the cones cross at their edges, the phenomenon of interference will be observed in its simplest form. In the centre of the screen will be seen a bright spot, and on either side of this a series of bands of alternate darkness and light. But light falls equally on the whole surface, so that here the addition of light to light has produced darkness. Where the waves of light that meet differ in length by one undulation, or by two, or by three, intensity results; but where the difference is $\frac{1}{2}$ a wave, $1\frac{1}{2}$, or $2\frac{1}{2}$ waves, the two will interfere, become neutralized, and darkness results. One aperture being closed, this interference ceases, and the black bands disappear. This phenomenon must be occurring everywhere during the continual crossing of the rays of light, but, owing to the general diffusion of light, it is not perceived by the eye until two small pencils are isolated in this manner.

If the above experiment be performed with white light instead of coloured rays, then another circumstance will result, depending on the different lengths and rapidities of the undulations in the seven coloured rays. One or other of these may be neutralized at a particular spot without the others being interfered with. The result is a succession of iridescent or coloured bands instead of a simple succession of light and darkness.

Interference may occur with reflected light. If a number of parallel extremely fine lines be drawn on the surface of a plate of polished steel, an iridescent surface is communicated to it. At regular intervals opposite the grooves there is no reflexion. The lines of reflected light interfere without compensation, and an interference of the rays and consequent bands of colour result.

The surface of mica, mother-of-pearl, many shells, the elytra of coleopterous insects, skin of fishes, and feathers of some birds, produce a brilliant play of colours in the same way by virtue of their texture. That this is the case is shown by our obtaining the same colours on an exact cast of such a surface in sealing wax, &c.

The iridescent colours of *thin plates* depend upon the interference of the rays reflected from the upper and lower surfaces

of such a plate or film. On account of its extreme thinness, the reflected rings may differ in length by the fractional part of an undulation, and thus interfere. Sir Isaac Newton produced a series of rings of colour by applying graduated pressure to two opposed plates of glass. The lower had a plane surface, the upper a double-convex lens of very slight convexity. There is between two such plates a thin layer of air increasing in thickness from the centre towards the circumference. The rays are reflected from the two surfaces of this film, and, knowing the convexity of the lens above, Newton was enabled to calculate the thickness of the film requisite to produce an interference resulting in a band of one particular colour. At and below the thickness of two-millionths of an inch, a black spot was produced, and above 72-millionths white light was reflected. The order of the colours between these points is termed *Newton's scale*.

The phenomenon of *diffraction* is seen on allowing a pencil of light to be reflected from a sharp edge on to a screen. An interference of the rays takes place on account of the interposition of the thin edge.

Place a lens l (fig. 282) of short focus in a hole of a window-shutter, and allow a pencil of light horizontally to enter the

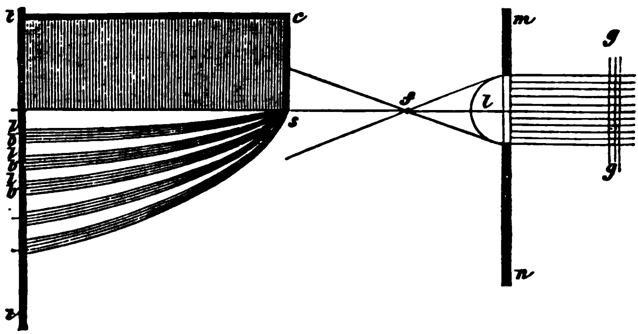

Fig. 282.—Diffraction of Light.

dark room through a glass $g\,g$, which will form a divergent cone; and that the light may more certainly be of the same nature, let it pass through coloured glass before entering the lens, which then will give but rays of one colour. Then at a

short distance from the focus put up a screen *c s*, having an edge clear and thin, let the bottom of this be on an exact line with the focus of the lens; at a distance from the screen place a piece of ground glass *t t*, the top of which may be on a level with the top of the screen, and it must at least be twice the length of the screen.

On the light passing through the lens, a shadow of the screen is thrown on the ground glass; on looking at this, although it proceeds in a straight line from the focus and bottom of the screen to the ground glass, yet the lower part of the shadow is not dark, but a degree of brightness rises upward, from the line, diminishing, however gradually, in intensity. Then below the focal line extended to the ground glass, there are seen alternate fringes or bands of light and dark; a bright one *l* first, then a dark one *b*, and so on, both gradually decreasing in intensity as they descend, until they become confounded with the light which passes by the edge of the screen. The bands all start from the edge of the screen, and in descending to the ground glass each describes a hyperbole.

These bands may be shown by all the tints of the spectrum; but if the red be commenced with, gradually as the tints descend to the violet, the fringes or bands lessen in width, and are closer together.

Now if a ray of white light pass through the lens under the same circumstances as above, that is, having a screen and ground glass, each colour of which white light is composed is diffracted, as if it were that only which is present. If we commence at the focal line on the ground glass, the violet fails first, and the red ought to come after the white fringe bordering the shadow; but at that part where the red fails when by itself, and the other colours do not, there is a mixed tint. Therefore the rule by which the bands of individual colours are governed, being known by the order and nature of the tints given by white light, can be determined.

The presence of the lens to concentrate the rays is not at all necessary to this phenomenon; to show this, we will suppose the arrangement to be as shown at fig. 283, only that at a short distance from the focus, a fine wire *w w* be placed in the course of the rays; the geometric shadow would then reach to *s s*, or the ground glass screen *t t*. Beyond this, on each side, *t s*, *s′ t′*, fringes may be seen, resembling those arising

from the edge of the screen in fig. 282, and are called *exterior fringes*; in addition to which, *interior fringes* occupy the whole width of the shadow, presenting with white light colours of various tints.

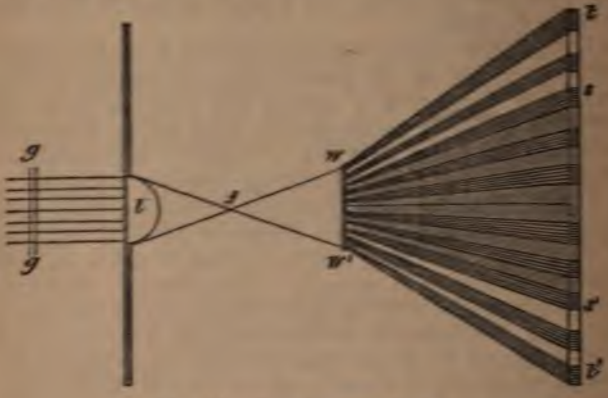

Fig. 283.—Interference of Light.

Dr. Young's ingenious theory of the principle of *interference* (first enunciated by him about 1801), may be said to have overturned the *molecular* and established the *wave* theory of light. This he demonstrated by making an experiment of the kind mentioned above. The rays of the sun (previously for convenience brought into a horizontal direction by a mirror outside) were admitted into a dark room through a *pin-hole*. Upon a table just beneath the level ray, were disposed some little moveable card screens, which could intercept the whole or part of it. This constituted the whole apparatus. One larger screen was placed at a considerable distance, and was wholly illuminated by the beam of light. Between this and the pin-hole, the others could be shifted to different distances, or moved sideways as occasion required. When any one of them was placed so as to intercept a part of the light by its edge, its shadow on the permanent screen presented the external fringes of Grimaldi and Newton. But it was on the internal bands that Young fixed his attention, which, when a narrow slip of card was used, ran parallel to the sides,

of the same breadth throughout, alternately dark and bright that which occupied the exact centre being always bright.

Young perceived at once the bearing of this fact. The beam of light was to his mind's eye a series of waves propagated onward from the pin-hole. The card acted merely as an obstacle; round its edges sets of waves diverged anew; and by their crossing and mingling with each other in alternate points, reinforced or neutralized each other; thus giving a series of dark and bright spaces. Conclusive subsequent experiments proved this to be the true explanation; which was readily extended to the *external* interference of the new waves with the original set at each side.

Fresnel subsequently extended the analytical details of the theory, and made several important improvements in the mode of conducting the demonstration. One of the most material improvements was this; it was held that the edge of the intercepting body exerted itself some peculiar action on the rays. To disprove this, he devised a simple and decisive experiment, in which no material substance whatever was interposed, but two streams of light were made simply to act on each other.

Light originating from a single luminous point was divided into two streams by being reflected from two plates of glass having the slightest imaginable inclination to each other, or transmitted through a plate of glass, one of whose surfaces was cut with two faces having the like small inclination; the two streams thus crossed at an extremely acute angle, and at the point of intersection exhibited a distinct and vivid set of dark and bright stripes, by means of an eye-piece having its focus at the intersection. In this case the interference is exhibited in perfect simplicity and independence; and in the full effulgence of the united illuminations of the two lights, the alternate intervals are as intensely black as if the rays were shut out by the most impenetrable screen.

The principle of interference is characterized by the high generality of its application. Once recognized, it connected by a common law all the diversified effects hitherto imagined due to an equal diversity of causes,—the colours of thin films; the diffracted bands; the colours of fine dew, and fibres of narrow groves, of mother-of-pearl, investigated by Young and Brewster, as afterwards those of gratings and apertures applied

to the object-glass of a telescope by Fraunhofer: while by another application it was found to obviate the objection which the *rectilinear* course of light opposed to the wave theory: and later instances of bands formed by partial interception of the prismatic spectrum, observed by Brewster, Airy, and Powell, and the elaborate calculations of nearly all possible combinations of diffractive phenomena by Schwerd, have afforded equally successful proofs of its fertility. The undulatory theory, defective as it may be, is not only the best, but the only theory we have.

Diffraction.—For showing the phenomena of diffraction of light, a convenient form of apparatus has been devised by Mr. John Bridge, consisting of a lens placed in an aperture in a dark screen, on which direct sun-light is reflected by a mirror. When the image of the sun in the focus of the lens is viewed, by a small telescope, through transparent apertures of various shapes in an opake film of collodion, produced by photography, the effects produced are extremely varied and beautiful.

The brilliant tints of soap-bubbles, and of thin plates of various transparent bodies, afford further examples of interference of light: for the undulations reflected from their first surfaces interfere with those reflected from the second; and upon the amount of retardation thus experienced by the luminous waves, the varieties of colours observed in these thin plates depend.

The *interference of light* has opened up to the chemical philosopher a wide and promising field of interest. It has lately been shown in a beautiful series of experiments made by Professors Bunsen and Kirchhoff, that we possess an accurate method of chemical analysis by spectrum observations.

This exquisite method of qualitative analysis is founded on the power possessed by many substances of developing peculiar bright lines in the spectrum of a flame in which they are introduced. The bright lines produced in this manner show themselves most plainly when the temperature of the flame is highest and its illuminating power least: hence Bunsen's gas-burner, which gives a flame of very high temperature and very slight luminosity, is well adapted for experiments on the bright lines of the flame-spectra.

The apparatus employed by Messrs. Kirchhoff and Bunsen

in their spectrum observations is thus represented and described in Poggendorff's 'Annalen.'

A (fig. 284) is a box blackened on the inside, having its horizontal section in the form of a trapezium, and resting on three feet; the two inclined sides of the box, which are placed

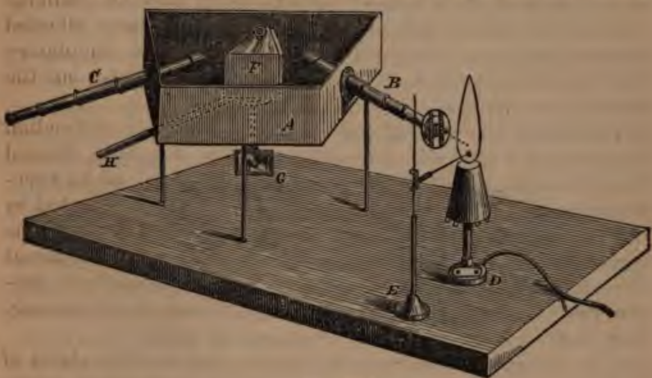

Fig. 284.

at an angle of about 58° from each other, carry the two small telescopes B and C. The eye-piece of the first telescope is removed, and in its place is inserted a plate, in which a slit made by two brass knife-edges is so arranged that it coincides with the focus of the object-glass. The gas-lamp D stands before the slit in such a position that the mouth of the flame is in a straight line with the axis of the telescope B. Somewhat lower than the point at which the axis of the tube produced meets the mouth, the end of a fine platinum wire bent round to a hook is placed in the flame. [The common spirit-lamp answers the purpose equally well: the salt should be either mixed with the spirit or introduced into the cotton wick.] The platinum wire is supported in this position by a small holder E, and on to the hook is melted a globule of the dried chloride which it is required to examine. Between the object-glasses of the telescopes B and C is placed a hollow prism F, filled with bisulphide of carbon, and having a refracting angle of 60°; the prism rests upon a brass plate, moveable about a vertical axis. The axis carries on its lower part the mirror

e, and above that the arm H, which serves as a handle for turning the prism and mirror. A small telescope placed some way off is directed towards the mirror, and through this telescope an image of a horizontal scale fixed at some distance from the mirror is observed. By turning the prism round every colour of the spectrum may be made to move past the vertical wire of the telescope C, and any required position of the spectrum thus brought to coincide with the vertical line. Each particular portion of the spectrum thus corresponds to a certain point on the scale. If the luminosity of the spectrum is very small, the wire of the telescope C may be illuminated by means of a lens, which throws a portion of the rays from a lamp through a small opening in the side of the tube of the telescope C.

From a long series of preliminary experiments with this apparatus, the authors satisfied themselves that the appearance of certain bright lines in the spectra may be regarded as absolute proof of the presence in the flame of certain metals, and that they serve as reactions, by means of which these bodies may be recognized with more certainty, greater quickness, and in far smaller quantities, than can be done by help of any other known analytical method, no matter what may be the nature of the body with which the metals are combined.

The wonderful delicacy of the spectrum-reaction of *sodium* is evinced by the following experiment. In the experiment room, the capacity of which is about 60 cubic metres (one cubic metre = 35·3 cubic feet), was burnt a mixture of 3 milligrammes (0·0462 gr.) of chloride of sodium with milk-sugar, whilst the non-luminous flame of the lamp was observed through the slit of the telescope. Within a few minutes the flame, which gradually became pale and yellow, gave a distinct yellow sodium line, coincident in the solar spectrum with Fraunhofer's dark line D, lasting for about ten minutes, and then entirely disappearing. From the weight of the sodium salt burnt, and the capacity of the room, it was calculated that in one part by weight of air, there was suspended less than $\frac{1}{20000000}$ of a part of soda smoke. As the reaction can be quite easily observed in one second, and as in this time the quantity of air which is heated to ignition by the flame could be calculated from the rate of issue, and from the composition of the gases of the flame, the surprising result came out that

the eye is able to detect with the greatest ease quantities of sodium salt less than $\frac{1}{1000000}$ of a milligramme in weight. The reaction of *potassium* is not so delicate; the spectrum contains only two characteristic lines, one in the outermost *red*, and the other far in the *violet* ray of the solar spectrum—points at which the eye ceases to be sensitive to the rays. The presence, however, of $\frac{1}{1000}$ of a milligramme of the metal could be readily detected. *Lithium* gives two sharply defined lines—the one a very weak *yellow* line, and the other a bright *red* line, both towards the extreme red end of the solar spectrum; though the reaction is not so sensitive as with sodium, it is by far the most delicate test for the metal, the eye being capable of distinguishing with absolute certainty a quantity of carbonate of lithium less than $\frac{9}{100000000}$ of a milligramme in weight. The authors found to their surprise that lithium, instead of being a rare substance, was a very widely-distributed one, occurring in almost all bodies. They found it in the water of the Atlantic; in the ashes of marine plants; in pure spring water; in the ashes of tobacco, vine-leaves, and of grapes; and even in the milk of animals fed on crops growing in the Rhine plain, on a non-granitic soil. *Strontium*, *barium*, and *calcium* all give characteristic spectra; that of *strontium* is characterized by the absence of *green* bands. It contains, however, eight remarkable ones, namely, six *red*, one *orange*, and one *blue* line. To examine the intensity of the reaction, Kirchhoff and Bunsen threw up into the air of the room, in the form of fine dust, 0·077 grm. of the chloride, and thoroughly mixed the air by rapidly moving an umbrella; the lines immediately came out, and realized the presence of the $\frac{6}{100000}$ part of a milligramme of strontium. The *barium* spectrum is distinguished by two very distinct *green* lines, by which the authors were enabled to detect with certainty $\frac{1}{1000}$ of a milligramme of the metal. *Calcium* gives a broad and very characteristic *green* line, and moreover, a bright *orange* line lying near the red end of the spectrum. $\frac{1}{10000000}$ of a milligramme of the chloride of the metal could be easily detected. It is particularly worthy of note that the spectra-reactions of different metals do not interfere with one another; that each being characterized by some one or more special lines, it is easy to make a qualitative analysis of a compound containing several elements: thus, Kirchhoff and Bunsen were enabled to

exhibit the reactions of *potassium*, *sodium*, *lithium*, *calcium*, and *strontium*, in several mineral waters: to show the bands of *sodium*, *potassium*, *lithium*, and *calcium* in the ash of a cigar moistened with hydrochloric acid, and to point out differences in the composition of various limestones. But the greatest triumph of the new method of analysis was the discovery of another member of the group of alkali metals. While working on the residue of a mineral water from Kreuznach, a spectrum was obtained which gave lines as simple and characteristic as those of lithium and sodium, but which were *blue*, and were not referable to any known element: these indefatigable chemists evaporated down no less a quantity than *twenty tons* of the water, and obtained 240 grains of the platinum salt of the new metal, which they call *cæsium*, from the Latin word *cæsius*, signifying greyish blue, that being the tint of the two spectral lines which it shows. The new metal is very analogous to potassium, but differs from it in the solubility of its nitrate in alcohol. Its equivalent number is 117, being exactly three times that of potassium. It is scarcely possible to overrate the probable importance to chemical science of this new and beautiful method of analysis. "In spectrum analysis," observe the authors, "the coloured bands are unaffected by any alteration of physical conditions, or by the presence of other bodies. The positions which the lines occupy in the spectrum indicate the existence of a chemical property as unalterable as the combining weights themselves, and may therefore be estimated with almost astronomical precision: it extends almost to infinity the limits within which the chemical characteristics of matter have hitherto been confined. By an application of the method to geological inquiries, the most valuable results may be expected: it opens out, moreover, the investigation of an entirely untrodden field, stretching even beyond the solar system: for in order to examine the composition of a luminous gas, we require, according to this method, only to see it: and it is evident that the same mode of analysis must be applicable to the atmosphere of the sun and of the brighter fixed stars."

Polarization of Light.

Huyghens and others having observed that a ray of light has not the same properties in every part of its circumference,

compared it to a magnet, or a collection of magnets; and supposed that the minute particles of which it was said to be composed had different poles, which, when acted on in certain ways, arranged themselves in particular positions; hence the term *polarization*, a term having neither reference to cause nor effect. It is to Malus, however, who, in 1808, discovered polarization by reflexion, that we are indebted for the series of splendid phenomena which have since that period been developed; phenomena of such surpassing beauty as far to exceed any thing which can be presented to our eyes under the microscope. It has been truly observed by Sir David Brewster, that "the application of the principles of double refraction to the examination of structures is of the highest value. The chemist may perform the most dexterous analysis; the crystallographer may examine crystals by the nicest determination of their forms and cleavage; the anatomist or botanist may use the dissecting knife and microscope with the most exquisite skill; but there are still structures in the mineral, vegetable, and animal kingdoms which defy all such modes of examination, and which will yield only to the magical analysis of polarized light. A body which is quite transparent to the eye, and which might be judged as monotonous in structure as it is in aspect, will yet exhibit, under polarized light, the most exquisite organization, and will display the result of new laws of combination which the imagination even could scarcely have conceived. In evidence of the utility of this agent in exploring mineral, vegetable, and animal structures, the extraordinary organization of apophyllite and analcime may be referred to; also the symmetrical and figurate depositions of siliceous crystals in the epidermis of equisetaceous plants, and the wonderful variations of density in the crystalline lenses of the eyes of animals."

If we transmit a beam of the sun's light through a circular aperture into a darkened room, and if we reflect it from any crystallized or uncrystallized body, or transmit it through a thin plate of either of them, it will be reflected and transmitted in the very same manner, and with the same intensity, whether the surface of the body is held above or below the beam, or on the right side or left, provided that in all cases it falls upon the surface in the same manner; or, what amounts to the same thing, the beam of solar light has the same pro-

perties on all its sides: and this is true, whether it is white light as directly emitted from the sun, or from a candle or any burning or self-luminous body; and all such light is called *common* light.

A *section* of such a beam of light will be a circle, like *a b c d* (fig. 255); and we shall distinguish the section of a

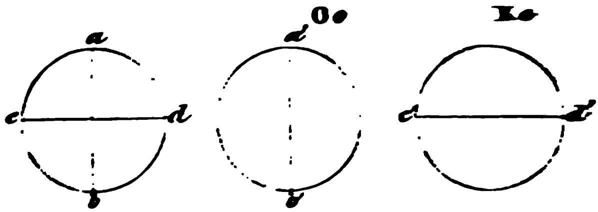

Fig. 255.

beam of common light by a circle with two diameters *a b*, *c d*, at right angles to each other.

If we now allow the same beam of light to fall upon a rhomb of Iceland spar, and examine the two circular beams O *o*, E *e* formed by double refraction, we shall find,—1st, that the beams O *o* E *e* have different properties on different sides, so that each of them differs in this respect from the beam of common light.

2nd. That the beam O *o* differs from E *e* in nothing excepting that the former has the same properties at the sides *a' b'* that the latter has at the sides *c'* and *d'*; or in general, that the diameters of the beam, at the extremities of which the beam has similar properties, are at right angles to each other, as *a' b'* and *c'* and *d'* for example.

These two beams, O *o*, E *e*, are therefore said to be *polarized*, or to be beams of *polarized* light, because they have sides or *poles* of different properties and planes passing through the lines *a b*, *c d*; or *a' b'*, *c' d'* are said to be the *planes* of *polarization* of each beam, because they have the same property, and one which no other plane passing through the beam possesses.

Now it is a curious fact, that if we cause the two polarized beams O *o*, E *e* to be united into one, or if we produce them by a thin plate of Iceland spar, which is not capable of separating them, we obtain a beam which has exactly the same properties as the beam *a b c d* of common light. Hence we infer that a

beam of common light, *a b c d*, consists of *two* beams of polarized light, whose plane of polarization, or whose diameters of similar properties are at right angles to one another. If O *o* is laid above E *e*, it will produce a figure like *a b c d*; and we shall therefore represent common light by such a figure. If we were to place O *o* above E *e*, so that the planes of polarization $a' b'$ and $c' d'$ coincide, then we should have a beam of polarized light twice as luminous as either O *o* or E *e*, and possessing exactly the same properties; for the lines of similar property in the one beam coincide with the lines of similar property in the other. Hence it follows that there are three ways of converting a beam of common light, *a b c d*, into a beam or beams of polarized light.

1st. We may separate the beam of common light, *a b c d*, into its component parts O *o* and E *e*. 2nd. We may turn round the planes of polarization, *a b c d*, till they coincide or are parallel to each other. 3rd. We may absorb or stop one of the beams, and leave the other, which will consequently be in a state of polarization.

For the purpose of producing the phenomenon of polarized light we employ a doubly reflecting crystal, made from a transparent mineral substance called *Iceland spar*, *calcareous spar*, *carbonate of lime* or calcite. Iceland spar is composed of fifty-six parts of lime and forty-four parts of carbonic acid; it is found in various shapes in almost all countries; but whether found in crystals or in masses, we can always cleave it or split it into a shape represented by fig. 286, which is called a rhomb of Iceland spar, a solid bounded by six equal and similar rhomboidal surfaces, whose sides are parallel, and whose angles *b a c*, *a c d*, are 101° 55′ and 78° 5′. The line *a x*, called the *axis of the rhomb* or of the crystal, is equally inclined to each of the six faces at an angle of 45° 23′. It is very transparent, and generally colourless. Its natural faces when it is split are commonly even and perfectly polished; but when they are not so, we may by a new cleaverage replace the imperfect face by a better one, or we may grind and polish an imperfect face.

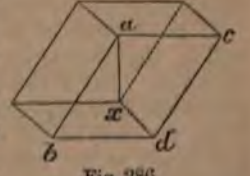

Fig. 286.

It is found that in all bodies where there seems to be a

regularity of structure, as salts and crystallized minerals, on light passing through them it is divided into two distinct pencils. If we take a crystal of Iceland spar, and look at a black line or dot on a sheet of paper, there will appear to be two lines or dots; and on turning the spar round, these objects will seem to turn round also; and twice in the revolution they will fall upon each other, which occurs when the two positions of the spar are exactly opposite, that is, when turned one-half from the position where it is first observed. In the accompanying diagram (fig. 287) the line appears double, as *a b* and *c d*, or the dot, as *e* and *f*. Or allow a ray of light *g h* to fall thus on the crystal, it will in its passage through be separated into two rays, *h f*, *h e*; and on coming to the opposite surface of the crystal they will pass out at *e f* in the direction of *i k*, parallel to *g h*. The plane *l m n o* is designated the principal section of the crystal, and the line drawn from the solid angle *l* to the angle *o* is where the axis of the crystal is contained; it is also the optic axis of the mineral. Now when a ray of light passes along this axis, it is undivided, and there is only one image; but in all other directions there are two.

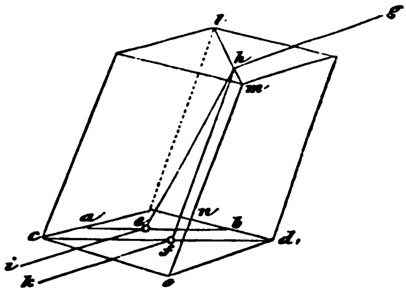

Fig. 287.

If two crystals of Iceland spar be used, the only difference will be, that the objects seem further apart from the increased thickness. But if two crystals be placed with their principal sections at right angles to each other, the ordinary ray refracted in the first will be the extraordinary in the second, and so on *vice versâ*: at the intermediate position of the two crystals there is a subdivision of each ray, and therefore four images are seen; when the crystals are at an angle of 45° to each other, then the images are all seen of equal intensity.

If we take a piece of that crystallized mineral called tourmaline, cut about $\frac{1}{20}$th of an inch thick, in a direction parallel to the axis of the prism, we see a candle through it as if it were

a piece of smoked glass, and no change in the candle takes place; but if we place another piece between it and the candle, and turn round slowly the first piece, the candle will appear to be shut off from view at every quarter; turn them gradually, and it will come again into sight, and again disappear. This arises from the axes of the pieces of tourmaline being different, and preventing the passage of the rays of light, only freely admitting them when the axes of both plates are parallel to each other. This Professor Whewell expresses as "opposite properties in opposite directions, so exactly equal as to be capable of accurately neutralizing one another."

Dr. Herapath has succeeded in making artificial tourmalines large enough to surmount the eye-piece of the microscope; so that all experiments with those crystals upon polarized light may be made without the tourmaline or Nicol's prism.

If, instead of viewing the reflected ray through a tourmaline, we place another plate of glass so that the reflected ray may fall upon it at the same angle as upon the first, this second plate may be made to turn round its axis without varying the angle which it makes with the ray which falls upon it. When the two planes of reflexion coincide with each other, the ray of light, or luminous object, will be reflected from the second glass in the same manner as from the first; but if we turn the second glass round a quadrant of a circle, so as to make the planes of reflexion perpendicular to one another, the whole of the ray will pass through the second glass, and none of it will be reflected. Let us turn the second glass round another quadrant, so as to make the planes of reflexion again coincide, and the ray will be again wholly reflected. When the glass has been turned round three quadrants, the light will be again extinguished.

As both the pencils of light into which a ray is divided by passing through a rhombohedron of Iceland spar are polarized, but in opposite directions, on viewing the reflexion of a lamp from glass, at the proper polarizing angle, through such a crystal, the two images will alternately appear and disappear as it is turned upon its axis.

It may perhaps assist our comprehension of the connexion of these phenomena to illustrate them by a rough analogy: a ray of common light as it is emitted from a self-luminous body we may conceive to revolve upon an axis coincident with its

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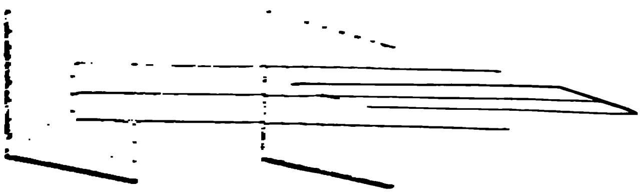


Fig. [illegible]

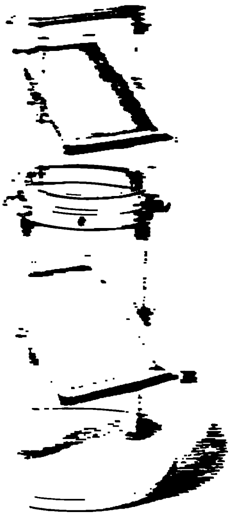
[illegible] passed freely between them, they would present an impassable barrier to the other, which would be presented to them crosswise. Supposing the grating to rotate round its axis, at the completion of the first quadrant the first would be arrested, and the second would pass; and so they would alternately pass and be stopped at each quadrant of the turn.

If with a plate of tourmaline we examine a polarized ray of

white light as it passes through a crystallized substance having a single axis, there are seen rings of various prismatic colours, that change as the position of the tourmaline is altered. On the axis of the tourmaline being brought into the plane of polarization, then a rich black cross is seen crossing the coloured rings; gradually as the tourmaline is turned, the black cross fades away; and when in the opposite direction, the white one supplies its place, and the second image is complementary to the previous one.

One of the most beautiful phenomena is that of causing a ray of polarized light to traverse a thin plate of mica or sulphate of lime, and then analyse with a plate of tourmaline in that particular position in which without the plate it would wholly disappear: the ray will appear coloured with the tints of the spectrum in vivid intensity, and these may be varied by giving different degrees of inclination to the plate. One of the most perfect specimens of this phenomenon that we have seen was a copy of a gorgeously plumed bird of the parrot tribe, made by Mr. Holmes. On looking at the plate there appeared only a kind of outline stuck upon it; but on placing it so as to receive the polarized ray, the brilliant red, purple, and yellow tints start forth as intense as in nature, with every feather as appropriately tinted. This was effected by carefully cutting away parts, so that different thicknesses of mica should be presented to the polarized ray. Instruments employed for the measurement of the angle of polarization are called *polariscopes*.

The most convenient mode of repeating the experiments of Malus, is by means of the apparatus represented in fig. 289. This consists of two uprights of wood, supporting a frame *k m*, constructed like a common looking-glass frame. A circular plate of wood, *g h*, rests on the pillars, and has a circular aperture in the middle about three inches in diameter; a ring of wood *e f*, moveable round a circular projection on *g h*, supports two pillars *a b*, between which rests, by means of screws, a frame *c d*, like *k m*, but somewhat smaller. A slip of paper graduated into 360°, is fixed on that portion of *g h* which projects beyond *e f*, a black line being marked on the latter, to serve as an index, and to point to zero on the graduated paper, when the pillars *a b* are exactly over the aperture in the centre of *g h*, to serve as a stage on which objects to be submitted to the action of polarized light may be placed.



[illegible]

[illegible] two portions [illegible] the plane of [illegible] passes through [illegible] being checked by [illegible] The other [illegible] and reflexion, is [illegible] and thence to the eye of the [illegible] an image of the candle. Then [illegible] keeping it at the same angle, by moving the [illegible] the wooden collar $c\,h$, and when d is at right angles [illegible] the image of the candle will almost entirely vanish. This might be indeed anticipated, for the ray reflected from l is polarized in the plane of reflexion: but this plane is now perpendicular to the plane of incidence on the upper plate

d, and as there is therefore no motion remaining to be resolved in that plane of incidence, no rays are reflected, but the polarized ray passes through the glass, and is absorbed by the black paint at its back; so that, in looking at *a b* in this position, scarcely a vestige of light is to be seen reflected from it. On moving *a b* round through another angle of 90°, the light and figure of the candle will reappear in *d*, as the planes of polarization and reflexion coincide, being both identical with a plane passing through *d l*. At the intermediate arcs of rotation, the light in *d* will decrease or increase in intensity, according as it approaches to, or recedes from, the position.

A very instructive mode of analysing the polarized ray after it has passed a film of selenite, is to transmit it through a rhombohedron of calcite; the transmitted ray will be divided into two coloured images, which will be both visible at the same time. The red and green images are complementary to each other, and, if superposed, would constitute white light; this may be proved by holding the calcite at a proper distance, when the two images will partly overlap each other, producing white light, as in fig. 290. On this account no colours were seen when the selenite was viewed without the analysing plate (fig. 289) or calcite, as *both* rays then reached the eye together, and produced a white image.

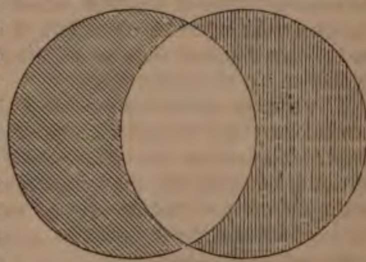


Fig. 290.

In the above experiments with selenite or mica, the rays of incident polarized light were nearly parallel; if, however, they are convergent, and enter a crystal so as to traverse its optic axis, a new and splendid series of phenomena becomes visible.

Let common light be incident on a plate or a series of plates of glass *a b* (fig. 291), placed on a black surface at the polarizing angle, so that a bright beam of polarized light may be reflected to the eye at *c*, which thus is placed at the apex of a cone of rays. If a thin plate of a double refracting crystal, as calcite, cut at right angle to its axis, be placed at *d*, it is obvious

that the rays of polarized light will traverse it with various degrees of obliquity, and thus virtually permeate different

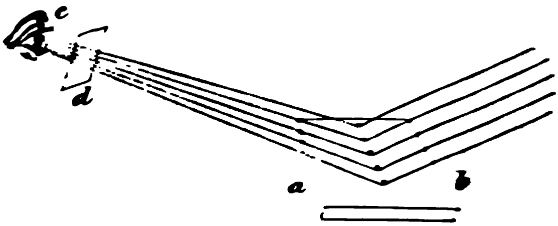


Fig. 291.

thicknesses of the section. The central rays which pass through the optic axis do not suffer double refraction, and therefore will appear to the eye at *c* the same as if no crystal had been present; but the other rays, which pass a little obliquely through the crystal, will undergo double refraction, each being resolved into an ordinary and extraordinary ray, as is the case with ordinary light.

These rays, however, reaching the eye together, will not produce any colour, and cannot be distinguished from common light. To render the phenomena of coloured polarization obvious, an analysing eye-piece must be placed between the plate of doubly refracting crystal and the eye. Let this be a plate of tourmaline or agate, so placed as not to transmit the polarized light reflected from *a b*, if the crystal *d* were absent. It will be found that the light reflected from *a b* has undergone some physical change whilst traversing *d*, as some of it has acquired the power of passing through the analysing plate of tourmaline, and a beautiful symmetrical image, painted with the most gorgeous colours, becomes visible; this image is composed of a series of concentric coloured curves, and traversed by a black cross (fig. 293). Let the tourmaline be then turned round 90°, and an image complementary to the first will be visible, its black cross being replaced by a white one.

"The origin of these beautiful coloured rings," says Mr. Brooke, "may be thus explained: the rays which do not pass through the optic axis are divided into two pencils, an ordinary and extraordinary, polarized in different planes, and hence one series is absorbed and the other transmitted by a tourmaline

plate, according as it is held so as to transmit or absorb the originally polarized ray; but this, although sufficient to explain the production of two images, is not sufficient to explain the phenomena of coloured rings. It must be recollected that the rays pass through the plate of the crystal *d* with various degrees of obliquity, and hence some suffer more in the rapidity of their motion than others, or, in other words, undergo a different amount of retardation; the rays are thus placed in the very condition required for the phenomena of interference, and the consequent production of coloured fringes, as in the case of common light. The ordinary rays being polarized in the same plane, mutually interfere to produce one of the coloured images, and the extraordinary interfere to produce the other; the two images being complementary to each other, and, if superposed, produce white light. The figure of the rings results from the rays which penetrate the crystal at equal distances from the optic axis, passing through similar thicknesses of the plate, and consequently undergoing the same amount of retardation, and producing similar tints at equal distances from the centre. The singular appearance of the black cross is owing to the rays which traverse the crystal in the direction of the plains of primitive polarization emerging unchanged, and in these two directions the dark blue or black appearance presented by the reflector *a b*, fig. 291, when viewed through the analyser alone, will be visible as the arms of a black cross."

The beautiful figures visible in unannealed glass are rendered more brilliant by allowing the polarized ray to pass twice through the piece submitted to experiment. For this purpose, the very simple apparatus for polarizing light proposed by Lecount, can be conveniently employed; it consists of a small looking-glass *a* (fig. 292), placed on the table, and a frame *b* fastened to the mirror by a hinge at *c*, containing about ten plates of common plate window-glass, which is fixed in an inclined position to the mirror by means of a support *d*. The piece of unannealed glass is placed on the mirror, and it is viewed in the direction *e f*, when the figures become beautifully distinct, the rings being much more numerous than when examined in the ordinary manner. Common light is incident on *b* in the direction *g f*, and is divided into two oppositely polarized rays, one of which is transmitted, and the

other is reflected towards the mirror, passing in its course through the unannealed glass plate; from the mirror it is reflected black again, passing through the plate, and being partly depolarized, passes in part through the inclined glass plates, rendering the figure visible from *e*.

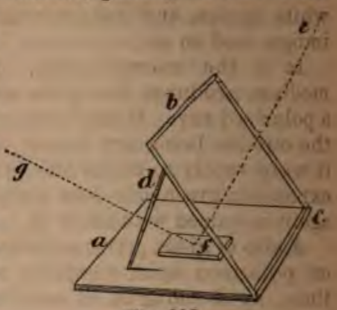


Fig. 292.

Jelly, solutions of gum, and albuminous fluids, allowed to evaporate spontaneously, so as to leave an indurated mass, also exhibit the four coloured sectors, traversed by a black cross.

Many crystals possess two optic axes; these constitute by far the greater portion of natural and artificial crystallized products. When the inclination of the axes is small, both systems of rings can be seen at once. To show these, take a crystal of nitre, and by means of a fine saw cut off a thick plate at right angles to the axis of the prism. The best mode of rendering this sufficiently thin, is to rub it on a fine file moistened with water. A plate one-sixth of an inch in thickness can thus be procured, and should be preserved between two thin plates of glass cemented together with Canada balsam. The two systems of rings are beautifully distinct, and splendidly coloured (fig. 293). When the line connecting the two axes of a crystal is inclined 45° to the plane of primitive polarization, the cross seen as first described on revolving the nitre opens and gradually assumes the form of two hyperbolic curves (fig. 294). But if the tourma-


Fig. 293.—Nitre.


Fig. 294.—Nitre.

line be revolved, the black crossed lines will be replaced by white spaces, and the red rings by green ones, the yellow by indigo, and so on.

It is the internal crystalline structure of a transparent medium produces the appearances seen on passing through it a polarized ray. Glass, when heated and suddenly cooled, from the outside being first hardened, and the inside struggling as it were vainly to mould the outside to its shape on losing the expansion given it by heat, presents a curious appearance; this again is varied with the form.

A slip of glass, previously without action on polarized light, developes a series of tints, by bending it or submitting it to pressure. Fig. 295 represents a square piece of unannealed glass; when a polarized beam is transmitted through it, there are seen at its four angles small circular figures separated by a large black cross. When the glass is rectangular the circular figures appear at the corners, and parallel to the greater sides, instead of the cross, there appear coloured bands.

Fig. 295.

When the shape is round (fig. 296) there are coloured rings and a large cross intersecting them; and as the shape is altered from square to round, or from round to square, so do the appearances change. When the glass is perfectly annealed, that is, cooled very slowly, these appearances are totally lost.

Fig. 296.

Circular polarization has discovered that the rays of each colour are polarized in different planes, and detected differences in the composition of substances that the utmost art of the analytical chemist could not discover; for by this light, it is not the mere structure but the nature of the particles that is elucidated.

One of the most interesting contributions to science, for which we are indebted to Dr. Faraday, is the discovery of the excitement of a molecular change in certain substances, as glass, water, alcohol, oil, when under the influence of the magnetic force, sufficient to cause the rotation of a polarized ray. To

show this with the magnet, a piece of flint-glass, a (fig. 297),

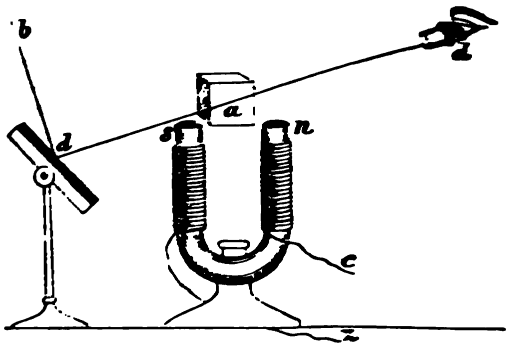


Fig. 297.

or much better, a slip of heavy glass, the fused borate of lead, 2 inches square and 0·5 inch thick, is placed between the poles *n s* of a powerful electro-magnet, so that the lines of force may pass through the length of the glass. A ray of light, *b d*, is polarized in a vertical plane by reflexion from a piece of blackened glass *d*, and passing through the glass *a*, is examined at *d* through a Nicol's prism. So long as the bars *n* and *s* are not magnetic, the ray is transmitted or extinguished as usual during the revolution of the prism. Let this be then turned so that the ray is darkened, then on connecting the wires *c z* with the battery, the bar instantly becomes magnetic, and the ray becomes visible. It will be necessary to revolve the prism to the right to extinguish the ray which has, under the influence of the developed magnetism, been made to revolve. If the north pole be next the observer, the ray will revolve to the right; but if this position be reversed, it will revolve to the left.

The polarizing apparatus shown in fig. 298 is both simple and useful for the examination of fluids, consisting of a bundle of plates of window-glass *c*, as a polarizing mirror, fixed to an arm, admitting of ready motion, and supported by a screw from a common retort-stand; immediately before this a narrow strip of silvered glass must be placed to receive the rays of light, from whence they are sent to the polarizing bundle of glass; above this is a tube of brass *b*, an inch in diameter,

and eight inches long, closed at its lower end with a plate of glass, and holding the fluid to be examined. The transmitted ray is analysed by an eye-piece *a*, consisting of a single-image prism, or bundle of thin glass plates, capable of being placed at any azimuth.

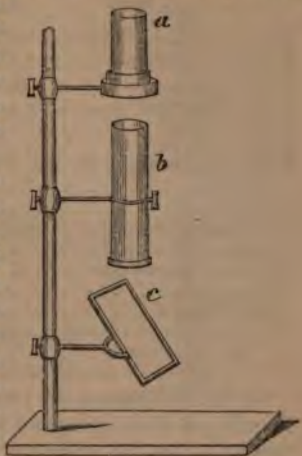


Fig. 298.

The action of oil of turpentine is much less intense than that of quartz, in the proportion of 1 to 68·5; hence the necessity of using a tube full of the oil, so as to form a fluid column about six or eight inches high. For some purposes it is desirable to use a tube of glass, in place of the brass tube *b*; and where the rotating power of the fluid is very feeble, a much greater length of tube than eight inches is necessary. Different substances, and sometimes different specimens of the same substance, rotate the plane of polarization in contrary directions. When the rotation takes place in the direction of the motion of the hands of a watch, the medium is said to have right-handed polarization.

Some organic products turn the plane of polarization from left to right; this is seen by using homogeneous light, which for practical purposes may be effected with sufficient accuracy, by observing the rotation through a piece of glass coloured red by protoxide of copper, and which transmits scarcely any except the extreme red rays. By operating in this manner, M. Biot has succeeded in detecting the property of circular polarization in a large number of fluids; and he has even applied this property to organic chemistry, as a mode of distinguishing between closely allied organic products, as the different varieties of gums and sugars. In the following Table are the results of Biot's experiments; the position of the points of the daggers in the third column indicates the direction of the rotation of the planes of polarization observed through red glass.

[illegible] by him:—"The [illegible] any convenient [illegible] from the sky is thrown [illegible] small plane mirrors S F, [illegible] the proper angle to the axis. It thence passes [illegible] aperture up the axis of the brass tube T T, in which is enclosed a common test-tube, from 6 to 12 inches in length, filled with the liquid under examination.

The analysing part A consists of a graduated rim W, for [illegible]uring the rotation of the index V, attached to the tube

containing a rhomb of Iceland spar R, at least one inch or three-fourths thick, in its natural state; having a small hole at the bottom of the tube, through which the light is admitted. In the upper part another tube slides carrying a lens L, which magnifies the separation of the images, and gives two sufficiently large well-defined circular images in which all the changes of tint can be accurately observed.

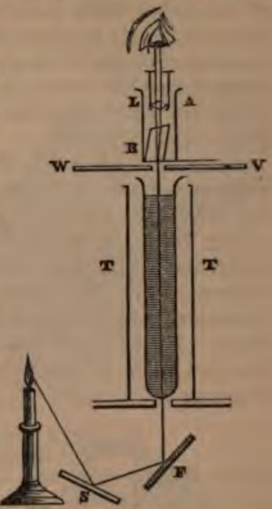


Fig. 299.

The wood supports are omitted in the figure; means should also be provided for measuring, as accurately as possible, the length of liquid traversed by the ray in the tube.

Mr. Woodward gave popular lectures on the polarization of light, which were afterwards published, with instructions for using his polariscope and microscope combined.

Mr. Woodward made use of an instrument so arranged that it is easily illuminated by a candle or argand lamp placed on the table, as in the case of an ordinary microscope; or with the addition of suitable condensers, it is attached to the lantern of the hydro-oxygen apparatus, and exhibited either as a gas polariscope or microscope in the lecture-room.

Fig. 300 is a brass cap fitting on at A, and enclosing a piece


Fig. 300.

Fig. 301.

of ground glass, to disperse the light of the candle or lamp used as an illuminator.

[illegible] Fig. 3[illegible] represents the [illegible] of the polariscope formed of two tubes [illegible] inches in diameter, each inclined at the polarizing angle of glass. [illegible] is the polarizing plate, consisting of [illegible] plates of thin white window-glass, the [illegible] being [illegible] to absorb the transmitted rays of light. These are attached to the [illegible] by screws [illegible] and can be removed at pleasure.

In fig. 3[illegible] [illegible] Fig. 3[illegible], and fixed by a bayonet-catch [illegible] the stage attached to and revolving around the tube [illegible] in position by the springs *c c*.

Fig. 3[illegible] is the magnifying power to be screwed into the stage [illegible] Fig. 3[illegible] [illegible] is composed of two lenses, the first being a plano-convex lens of [illegible] inches diameter and [illegible] inches focus, and the second, [illegible] of [illegible] inch diameter and [illegible] inches focus. By a crossed lens is understood a double-convex lens, the two sides of which are segments of circles of different diameters.

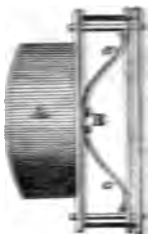


Fig. [illegible]

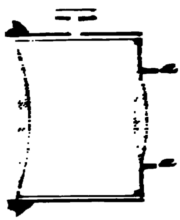


Fig. [illegible]

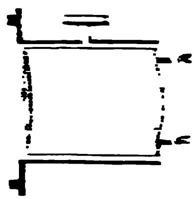


Fig. [illegible]

Fig. 3[illegible] is a higher magnifying power, composed of two crossed lenses, the first having a diameter of $1\frac{1}{4}$ inch and focus of $2\frac{1}{2}$ inches, and the second a diameter of $1\frac{1}{2}$ inch and focus of 2 inches.

Fig. 306.

The tourmaline, or other analyzing plate, is made to turn freely in a short tube *c c* (fig. 305), projecting from the eye-lens of the power: the focus is adjusted by a rack and pinion, or by sliding one tube in the other.

A box 9 inches high, and about 11 inches long by 7 wide, will contain the whole, and may be conveniently fitted as a stage to raise the polariscope

to a convenient height for illuminating and viewing objects on the table. Fig. 306 represents the apparatus properly connected and adjusted for use.

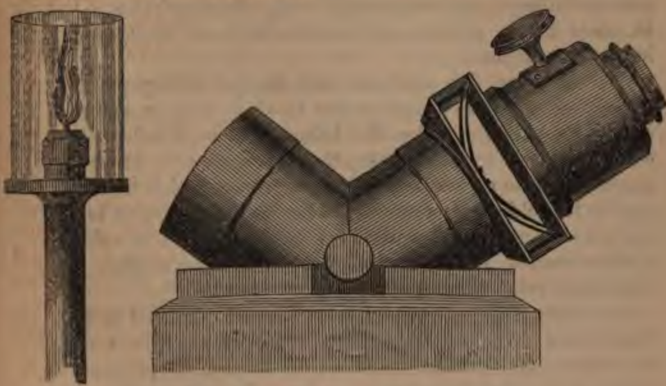


Fig. 306.—Woodward Polariscope.

The instrument arranged with the lowest power affords an extensive field of view, and is thus well adapted for exhibiting the various effects produced by the different forms and thicknesses of selenite and unannealed glass, and for illustrating the interesting phenomena of polarized light generally. It is also calculated for viewing such crystals of salts as have been allowed spontaneously to crystallize on glass; but the arrangement must be altered for observing the phenomena connected with the crystals of calc-spar, nitre, quartz, &c. In the first case, the lens or power is used to bring the image of the object to a focus; in the other, it is merely required to cause a great divergence of the rays passing through the crystals; hence the slide containing them must either be placed immediately between the eye-piece and analyser by means of a small stage attached to the tube *a a* of the power, or the stage and power must be removed, and there must be inserted instead, a double-convex lens of two inches focus, with a stage and analyser so arranged that the crystals may be placed just within the focus of the lens, and immediately under the analyser. In either case, a much larger field of view, and consequently a more beautiful display of coloured rays, will be developed than is

[illegible] microscope. A single plate of [illegible] may be occasionally laid on the bundle of [illegible] of a piece of chamois leather to [illegible] substituted with advantage as a polarizer [illegible] polarization is more important than [illegible]

[illegible] analyser and the polarizing plates, and [illegible] stop, with an aperture of [illegible] a silvered reflector, or in [illegible]-glass, the polariscope is immediately [illegible] of low power, which will include [illegible] of a large object, such as a butterfly [illegible] breathing apparatus of a dytiscus, [illegible] &c.; and thus exhibit at one [illegible] and connexions.

[illegible] the tints of polarized light more [illegible] crystalline lenses of animals, especially [illegible] these, they should, to prevent their [illegible] a focus, be immersed in a glass [illegible] or some fluid possessing nearly the [illegible] lens. The crystalline lens of the [illegible] coloured sectors, separated [illegible] polarization, and traversed [illegible]

[illegible] quills, and other indurated animal [illegible] tints, when submitted to the [illegible] beautiful manner.

[illegible] may be obtained by examining [illegible] or minute crystals, in a polar-[illegible] required for this purpose is to [illegible] an achromatic microscope a Nicol's [illegible] or a bundle of glass plates, when [illegible] the light transmitted through [illegible] will be rectilinearly polarized. The [illegible] Nicol's prism, fixed over the dia-[illegible] of the microscope; or as this must slightly [illegible] the achromatism of the instrument, the same, or [illegible] tourmaline, may be placed over the eye-glass. In this manner the molecular arrangement of quills, horns, hoofs, teeth, and other animal structures, is most beautifully developed.

A magnificent class of objects for the polarizing microscope is found in crystals of different doubly refracting bodies deposited on glass plates, by allowing their dilute watery solutions to evaporate spontaneously. To preserve them they should be covered with a second plate of glass, some Canada balsam being allowed to run between them. Chlorate of potass, nitre, salicine, acetate of lead, sulphate of copper, and ferrocyanide of potassium, are objects of really gorgeous beauty when thus examined. Other bodies, as calcite, exhibit the coloured rings traversed by a black cross, and are peculiarly beautiful.

The light of the sun reflected by the atmosphere is more or less polarized, depending upon the angular distance from the sun. If we look at the sky through a Nicol's prism, we shall find, on rotating the prism, that light from some parts of the sky is polarized to a very appreciable extent. Arago showed that some of the double stars were double suns, and other planets reflected light by polarizing the light from those bodies.

The *water-telescope* consists of an ordinary marine telescope, with a Nicol's prism inserted in the eye-piece. The light reflected from the surface of the water is the principal obstruction to viewing objects beneath its surface. Nicol's prism, in a certain position, entirely cuts off the polarized portion of the reflected light, and allows objects far below the surface to be seen with the telescope. Indeed the practical applications of polarized light are as numerous as the phenomena presented by it are deeply interesting; it aids in the analysis of animal, vegetable, and mineral structures, leading to a knowledge of which even the prediction is most startling. "If you can torture and twist a ray of light and prove it to have sides, the discovery may be a curious fact, but of what good is it to society?" Perhaps at first the discoverer might have been nonplused to find an answer; but we now know that, by looking through a piece of selenite at the northern sky, the solar time may be correctly ascertained. Place in the hands of a seaman a polarizing prism, and there need no longer be the purgatory of the mast-head, as from the deck the shoals and rocks at the bottom of the ocean may be seen. He whose livelihood depends on entrapping the denizens of the sea, may detect their whereabouts by observing the difference in the condition of the reflecting surfaces of the water. A glass may be known fitting to hold hot water, or that would break under

such conditions, by means of polarized light, as the annealed and unannealed present different aspects when so viewed. The unannealed piece of glass shown in a former page would easily break at every point where a set of the coloured rings are seen. The farmer may ascertain at what period his crop is richest in saccharine matter; the brewer and distiller know when their preparations are of the greatest excellence, and thus economize their time and labour, while they benefit by the superiority of their produce. By it, too, we know, from the colours exhibited in transparent or mineral substances, whether the sun's light comes from a solid mass or gaseous envelope, and whether the comets shine by their own or a borrowed light. Still, almost more wonderful are its powers of revelation in that department of science termed palæontology, as we can at once decide by a crystal or particle of bone, what the microscope alone cannot so accurately distinguish, whether the substance belonged to the fowl, flesh, or fish tribe; whether to a biped or quadruped, hoofed or clawed; to the mineral or vegetable kingdoms. What the ultimate results of this splendid discovery in science may be, it is impossible even to conjecture.

CHAPTER X.

ELECTRICITY.

Common or Frictional Electricity.

Five hundred and fifty years before the birth of Christ, Thales, one of the seven wise men of Greece, founder of the Ionic sect, which distinguished itself for its deep and abstruse philosophical speculations, discovered that *amber*, on being excited by friction, possesses the remarkable principle of attracting certain light bodies towards it, which he imagined to be a kind of animation peculiar to the substance.

The ancients were vaguely conversant with the influence which heat exercised on the production of electrical phenomena. Pliny—that repertory of the knowledge and ignorance of his time—mentions the hard violet, or deep red stone, which, when heated in the sun, or rubbed, attracts small light bodies. At the end of the seventeenth century, some Dutch merchants brought from Ceylon a peculiar stone, which was called *tour-*

namal, or *ash-attractor*, because, when placed upon heated ashes, it attracted them and then immediately repelled them, although with cold ashes no such effects were visible. This stone we now know as the mineral tourmaline. In 1757 Æpinus, having two polished tourmalines to set in a ring, instituted a series of experiments, and thereby established the first laws of the development of electricity by heat. He proved the presence of free electricity in the heated tourmaline, by the attraction and repulsion it successively exercised upon light bodies. He even drew a spark from it, which was visible in the dark. But the most important observation he made was of the simultaneous presence of *two* electricities in the same tourmaline, one being confined in one part, the other in another, these two constituting the electric poles. He further conceived that those electric poles, in the *unequally* heated tourmaline, are *contrary* to what they are in the equally heated tourmaline. Canton cleared up the contradictions by proving that it is not the absolute temperature, but the *change* of temperature which renders the tourmaline electric; the electricity of each pole varies according as the change is a heating or a cooling. Bergmann completed this view by showing that when the tourmaline is placed in a medium of its own temperature, whatever that may be, it is never electrical; transported into a colder medium, it immediately acquires the two electric poles, which state ceases as soon as the tourmaline, having abandoned its superior heat, is of the same temperature as the medium. This important law is not only true for the crystal as a whole, but equally so for each of its molecules separately, so that if the two poles are arranged so that one is heated while the other is cooled, they have the same electricity at the same time.

It is remarkable, that although the discovery of the existence of electricity is of very remote date, yet that hardly any attempts were made to inquire into its principles, and raise it to the dignity of a science, until the middle of the last century. From that period it has formed one of the most pleasing subjects of philosophical investigation, and its progress, consequently, has been most rapid; it has laid bare many truths in the secrets of nature, and now enters most intimately into the social affairs of nations.

Boyle is generally believed to have been one of the first

persons who produced the electrical light by rubbing a diamond in the dark. Otto Guericke, Dr. Wall, and Sir Isaac Newton, added somewhat to our knowledge on the subject. Mr. Gray, in 1729, made a variety of experiments that were corroborated by M. du Fay in Paris. In 1747 Franklin made several discoveries, and in 1752 succeeded in drawing lightning from the heavens and demonstrating that it was electricity. The "Transactions of the Royal Society" for the year [illegible] prove the industry with which Cavendish pursued the science, and the important results he achieved. To the discoveries of Galvani, followed by those of Volta at the close of the last century, we owe the commencement of the science termed Electro-chemistry; Davy's sedulous labours in analysis established it as one of the most useful branches of physical science. The experiments of Wheatstone have developed many wonders; and with the history of this science and electro-magnetism, discovered by Oersted, Faraday has imperishably linked his name to all posterity.

The term Electricity is derived from the Greek word *elektron*, signifying amber; in Latin *electrum*.

Nature of Electricity.

Electricity is a property of matter, or a power existing in it. It is an *imponderable agent*, and, like light and heat, does not admit of a distinct definition. Electricity appears to pervade all bodies to a greater or less degree, and when undisturbed produces no apparent effect; but when any body or part of a body becomes possessed of more or less than its natural quantity, it is said to be electrified, and is capable of exhibiting certain appearances. This would not be the case did all bodies receive and transmit it with equal facility. It is a distinguishing property of electricity that, under certain circumstances, it both attracts and repels, and communicates those qualities to different bodies. And, if two bodies equally electrified, but in *opposite* states, come into contact, they neutralize each other.

Friction applied to bodies possessing the same peculiarities as amber, is called *electrical excitation*; and bodies that are capable of being excited so as to produce electrical effects are named *electrics*. If we rub a piece of sealing-wax or glass rod on the sleeve of a cloth coat, or with a piece of dry flannel or

soft white silk, the wax or glass will attract towards them, and probably lift up, any light matter, as a feather, piece of tissue-paper, gold-leaf, straw, or cork.

A piece of writing-paper warmed, then laid on a table and rubbed with India-rubber, will be attracted to the table, and when raised from it will cause a slight crackling noise. When a silk stocking is worn over a woollen one, on taking off the silk one a slight snapping sound will be heard. The fur of a cat rubbed contrariwise in the dark will send forth sparks if it be warm and dry. These are all electrical phenomena.

If the windows of a flat shallow glass case be rubbed with a silk duster, the light dust inside will fly up against the glass and back again, and keep dancing in this manner while the rubbing is continued. Here we have in the first place attraction, and in the second repulsion, which causes the dust to be driven back. It was this simple occurrence that called Sir Isaac Newton's attention to the subject.

The two Electric Forces.

If two small balls turned out of elder pith and hung by a silken thread be brought within a short distance of an excited glass tube, they will be attracted towards it and remain against it; but when the tube is gently moved away from the little balls, they fly off from each other and keep apart for some time,—in fact, until their electricity is dissipated in the air. When still under the influence of the electricity, if the tube be brought again near them, instead of being attracted as before, they are farther repelled. Thus it appears at first the tube attracted the balls and imparted a portion of its electricity; but when applied a second time, they had sufficient of that kind of electricity, and moved away or were repelled.

We use the words "that kind," because if a roll of excited sealing-wax, sulphur, or shell-lac be presented to the balls, they would be attracted; and the same would occur if the last electrics had been used first and the first last. From this we learn there are two different kinds of electricity, possessed of opposite properties: that produced by excited glass, to which the name of *vitreous* or *positive* electricity has been given; and that produced by excited sealing-wax, to which the name of *resinous* or *negative* electricity has been applied. The positive and negative states of electricity attract each other, and when

they meet electrical equilibrium ensues. By friction of two substances together, as fire and glass, equilibrium is destroyed in each; the positive electricity accumulates in the glass, the negative in the fire. What one attracts the other repels, and *vice versâ*.

When sufficiently near for their attractive powers to come into action, the opposite electricities throw aside any non-conducting medium that may intervene. Thus in the heavens, when they come within what is termed the striking distance, the air is suddenly rent, thunder is heard, lightning produced, and an equilibrium of the electrical state of the atmosphere ensues.

The mode in which experimenters ascertain the kind of electricity in an excited body is this: they electrify a substance with a known electricity, vitreous or resinous, or what is the same thing, positive or negative, and then, as the body they electrify with the electricity with which they are engaged attracts or repels the other body possessed of the known electricity, it can be decided what the applied electricity is. Suppose some electricity be drawn from the clouds and a pith-ball be charged with it, and another pith-ball be vitreously electrified, then by bringing the cloud-electrified pith-ball to the other, if they are repelled the cloud-collected electricity will be positive, but if they are attracted to each other, then the atmospheric electricity will be negative.

No explanation can be given of the cause of the different species of electricity arising from various substances; all that is known is the fact, and that the body rubbed and the body rubbing become possessed, the one of positive, the other of negative electricity.

Conduction of Electricity.

If, when a pith-ball is electrified either with excited glass or sealing-wax, we touch it with a rod of glass, its property of being subsequently attracted or repelled by the excited glass or wax will suffer no change; but if we touch it with a rod of metal, it will lose the electricity which it had received, and will be attracted either by the excited glass or wax, as it was when they were first applied to it. Hence the rod of glass and the rod of metal possess different properties, the former being incapable, and the latter capable of carrying off the

electricity of the pith-ball. The metal is therefore said to be a *conductor*, and the glass a *non-conductor* of electricity.

A non-conductor does not suffer electricity to pass from one part of it to another. For instance, a piece of glass may be excited only in one part, without the other being at all under the influence; and if the whole surface of a tube be excited, it can be felt by sparks in various parts; and if an unexcited piece of glass be placed against an excited piece of glass, the electricity is not conducted away. The case is different with conductors; for if a rod of iron be suspended by a silken thread and charged, as soon as it comes near a body, that body will receive its overplus of electricity, the whole passing out in a single spark instantaneously. The same is the case with the human body. To receive a charge of electricity the conductor or the person has to be what is termed *insulated*; that is, by means of non-conductors cut off from all electrical communication with any substance, that would conduct the electricity rapidly to the earth. For this purpose a stool with glass legs is found the most convenient contrivance for the human body. Thus non-conductors are also called *insulators*.

Conducting bodies are not readily excited by friction. The best electrical bodies, or non-conductors, are gutta percha, shell-lac, sulphur, amber, resinous substances, jet, glass, and vitreous substances, precious stones (the most transparent the best), minerals, silk, dry external substances, as wool, hair, feathers; paper, parchment, leather, porcelain, loaf-sugar, dry gases, the air, marble, oils and dry metallic oxides, chalk, lime, phosphorus, steam of great elasticity, ice below 0° Fahr.

The principal electrical conductors, or non-electrics, are silver, copper, lead, gold, brass, zinc, tin, platinum, iron, and other metallic substances; well-burned charcoal, plumbago, concentrated and diluted acids, saline solutions, metallic ores, the fluids of an animal body, water, especially salt water, and other fluids, except oils; ice above 13° Fahr., snow, living vegetable and animal matter, earthy substances, flame, smoke, steam of low pressure, hot fluid resin, and hot glass.

Thus it is seen that the substances in nature from which electricity can be readily excited are non-conductors, and other bodies that are rapid conductors of electric action are non-electric. There are, however, no bodies that entirely

prevent or perfectly conduct electric action, the whole being merely a question of degree of capacity.

Electric Induction.

It has next to be observed that common electricity, when excited in one body, may be communicated by it to another without either contact or friction. If an excited glass rod be brought close to one end of an insulated horizontal rod of metal, the metal will become electrical, as evidenced by the divergence of pairs of pith-balls hanging from either end. But this state of excitement only continues while the glass rod is near. Remove it, and it instantly ceases, the pith-balls collapsing. It is *induced* by the neighbourhood of an excited body, which disturbs the equilibrium of electric force in the non-excited body. The electric force attracts that of an opposite nature, and repels that of the same kind as itself. The vitreous electricity of the glass causes the end of the metal rod near it to be resinously, *i. e.* negatively electrified, the other or remote end being positively electrified at the same time. On removing the cause induction ceases, and equilibrium is restored.

But let the metal rod be divisible into two parts, touching each other, and let them be separated while the glass rod is still near (without touching them with the hands). They will now remain electrified, the one negatively, the other positively, after the rod is removed. On bringing them near, equilibrium is restored with a spark.

Prof. Faraday conceives that the particles of air and other non-conducting matter in the vicinity of a charged body become arranged in a polarized manner, the half near the charged body exhibiting electricity of the opposite kind, the remote half of each retaining electricity of the same kind as that of the excited or inducing substance.

A highly charged body about to discharge itself, does so by first inducing electricity of an opposite kind in some substance or part of the earth near it. The two opposed electricities, when sufficiently near, neutralize each other with a spark.

Frictional Electricity.

We have thus glanced at some of the phenomena of electrical action that may be created by means of friction on a

glass tube; but as that method excited only a small quantity of electricity, the electrical machine was invented, whereby a large amount of electricity may be placed at command with little trouble and cost. The machines, although differing in construction, are the same in principle. Electricity is excited by the friction of a rotating glass surface against a rubber, and collected for use on an insulated metallic conductor. We proceed to describe the machine in most common use, fig. 307.

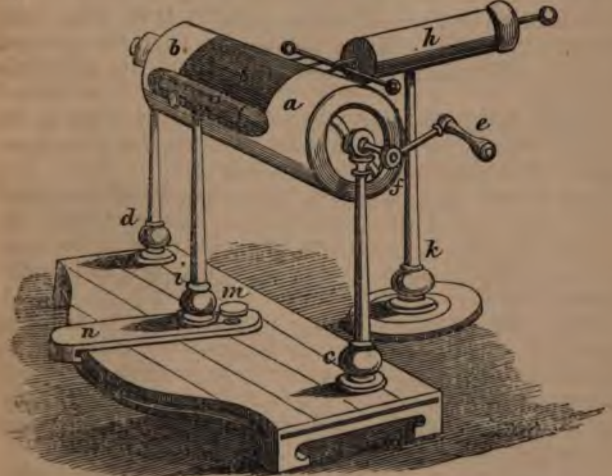


Fig. 307.—Electrical Machine.

a b is a hollow cylinder of glass, from 4 to 20 inches in diameter, and from 6 to 18 inches in length, having pivots projecting and made to revolve in round pieces of wood or metal cemented on upright glass pillars *c d*, which, as well as supporting, insulate the cylinder: this is driven round by means of a winch *e*; *g* is a cylinder of wood covered with tinfoil, supported on a glass pillar *i*, which by means of a groove and screw *m*, at the bottom, can be eased from or pressed against the cylinder of glass. Fastened to the wooden cylinder, and resting with a perfect but gentle pressure against the glass cylinder, is a cushion or rubber stuffed with horse-hair and covered with chamois leather. This cushion is rubbed over with an amalgam

of 1 part of tin, 2 of zinc, and 4 of mercury. They are separately melted and then mixed. When cold the amalgam is a semifluid mass, and can be spread on the cushion. To the cushion is sewed a flap of oiled silk, which lies loosely over the top of the cylinder. On the opposite side is another conductor and points, where the positive or vitreous electricity is collected as it escapes from underneath the silk flap. Both the cylindrical conductors are insulated by being placed on pillars of glass. The apartment in which experiments are made must be dry, and should be warm; and the glass parts, acting as insulators, must be coated with a solution of shell-lac in rectified spirits, and when used should be perfectly free from dust.

A chain is attached to the rubber and allowed to rest on the ground, whence the negative electricity is discharged into the earth. If this chain be withdrawn and attached to the other, which is named the prime conductor *h*, then the positive or vitreous electricity is carried off, and negative electricity is obtained from the other conductor *g*.

Fig. 308.

When the machine is turned in a dark apartment, its appearance is most beautiful. The conductors being removed, brilliant sparks and streams of vivid light pass from the termination of the flap around the under part of the cylinder to the rubber; a pointed rod of iron held at some distance from the cylinder, in a line with the end of the silk flap, will cause a bright light to be seen as if coming out of the iron point. If points be presented to both conductors at one time, there may be observed at the point presented to the prime conductor *h* a star of light, and at the point presented to the negative conductor the appearance will be like a bright brush or pencil of light, as seen in fig. 308.

If a person standing near to the conductor place his hand upon it when the machine is being worked, there will be no signs of electricity, because it flows silently through his hand and body to the earth; but if he stand on a stool having glass

legs, then, the passage of the electricity being stopped by non-conductors, sparks may be drawn from him as from the conductor itself.

If a hole be made in the knob at the outward end of the prime conductor, and a tuft of feathers placed in it, then, the machine being worked, the feathers will stand erect and endeavour to avoid each other; as each is electrified by the same electricity, they repel one another.

Fig. 309.

The phenomena of attraction and repulsion are well shown by the little apparatus known as the electric bells (fig. 309). They are suspended by the hook from the end of the prime conductor h; the two outer bells are hung by brass chains, while the central one with the two clappers on either side hang from silken strings; the middle bell being connected with the earth by a thin brass chain. On turning the cylinder the two outside bells become positively electrified, and by induction the central one becomes negative, a luminous discharge taking place between them if the electricity be in too high a state of tension. But if the cylinder be slowly revolved, the little brass clappers will become alternately attracted and repelled by the outermost and inner bells, producing a constant ringing as long as the machine is worked.

Fig. 310.

Let a metallic plate be suspended from the conductor, and underneath it, at a distance of three or four inches, let another plate (fig. 310) be placed; then if some pieces of paper in the shape of the human figure, and a number of small pith-balls, be laid upon the lower one, and the machine set in motion, the little figures and balls will jump to the upper plate, then be repelled, and go on dancing up and down as if alive.

There are many other pleasing and elegant experiments to be performed with the aid of the electrical machine, a few of which we shall describe.

Barker's spotted tube is a pretty instrument. It is a glass tube, well rounded at one end and open at the other, about ten inches long and three quarters of an inch in diameter; a smooth piece of tinfoil is fixed at the upper closed end, and spangles of tinfoil are placed in a spiral form around the tube from end to end (fig. 311). A cap of brass is cemented on the outside of the lower end of the tube, and a strip of foil placed round it. From this ring four wires project outwards, having their points bent at right angles. The tube is then set on an upright wire which passes upwards into the tube to its top, and this wire is then set on an insulated stand, and brought near the prime conductor, when it turns round and presents a most vivid appearance.

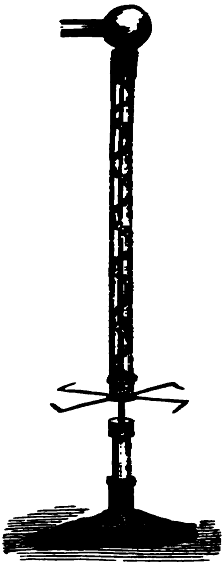


Fig. 311.

Place *a* (fig. 312) so as to receive sparks from the prime conductor; pour cold spirits of wine into *c* just sufficient to cover the bottom of the vessel, and set it under the wire *b*; turn the machine, and the spirits will be set on fire.

Take a cake of resin or shell-lac, and after exciting it write with the knob of a jar charged with positive electricity a word on the cake, then scatter on it an equal mixture of finely-powdered sulphur and red lead; the sulphur will fly on to and attach itself to the writing, while the lead separating will cover the other parts of the resinous cake. The effect of this experiment is both beautiful and interesting.

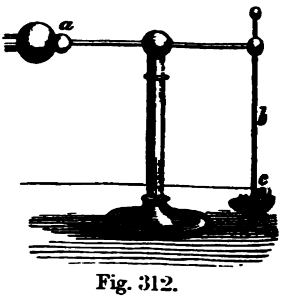


Fig. 312.

The *electrical planetarium*, re-

presented in fig. 313, is connected with the prime conductor by means of a chain; and when the machine is set in motion, the reaction of the air against the points a and b on the wires of the apparatus, causes it to move: the large ball representing the sun, the earth revolves round it, and the moon round the earth and sun. This experiment serves to illustrate the force of the current of air which accompanies the discharge of electricity.

Fig. 313.

Fig. 314.

If a small pail, with a spout near the bottom (fig. 314), in which there is a hole just large enough to let the water out by drops, be filled with water, and fastened to the prime conductor, on turning the machine the water will fly from it in a stream, and in the absence of light seem to be a stream of fire. This is accounted for by the mutual repulsive property of similarly electrified particles.

Attraction and repulsion are also amusingly seen in the *electrical swing*: the insulated brass ball a (fig. 315) is connected with the prime conductor, while the opposite ball b communicates with the earth; the little figure on the silken cord is drawn towards a, where it receives a charge which it discharges on swinging to b, then returns to a, and so continues in active exercise.

Fig. 315.

a small strip of wood ... insulated on *a* like a ... at *a*, so that it

... is a similar ... with the prime conductor, and the ...

... that instead of the ... of a circular ... machines ... consists of ... diameter ... inches each in length ...

... was very strong.

The plate-machine is now frequently used; and one of ... feet diameter, turned by a steam-engine, was for some time exhibited at the Polytechnic Institution. The accompanying diagram (fig. 517) illustrates the peculiar features of the plate machine, which consists of a large circular disc of glass supported upon two upright pieces of mahogany. The rubbers are on each side, and the insulation is effected by two pillars of glass. The conductor is usually made of metal, with two arms terminating in points, and supported by strong pieces of glass.

A curved brass tube acts as the negative conductor and connects the cushions.

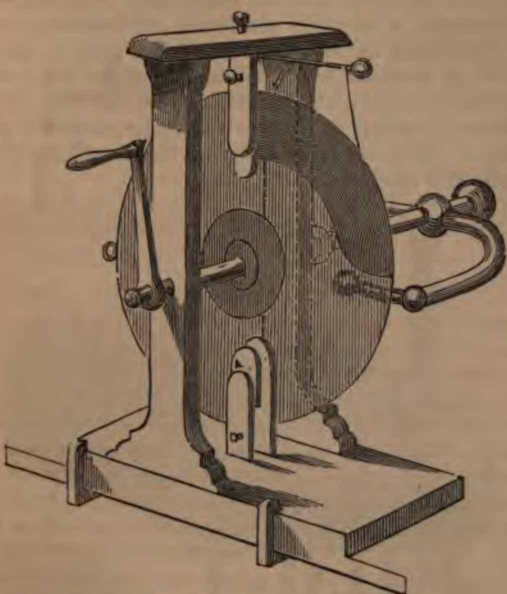


Fig. 317.—Plate Electric Machine.

Great power can be obtained by these machines; and as their surfaces can be easily reached, they are kept more perfectly dry than those of the cylindrical form. Excellent and economical machines are now made by covering a disc of wood with a thin sheet of gutta percha.

Hydro-electric Apparatus.

Electricity is as yet a young science, and every day brings forth some discovery in relation to it; one of the most remarkable is that of the possibility of generating it from steam —a machine for which purpose was used for some time at the Polytechnic Institution.

A workman at Seghill colliery, near Newcastle-upon-Tyne, having to adjust a safety-valve in consequence of an escape of

steam, was astonished on feeling a powerful spark of electricity when one of his hands was in the vapour, which proceeded from the boiler and the metal-work connected with it. Mr. Armstrong, a scientific gentleman at Newcastle, immediately commenced an investigation of the subject, and found that with an insulated brass rod, having at one end a ball and at the other a metal plate, he obtained from it 60 to 70 sparks per minute; the ball being near the boiler, and the plate in the steam. This led ultimately to the construction of the hydro-electric machine.

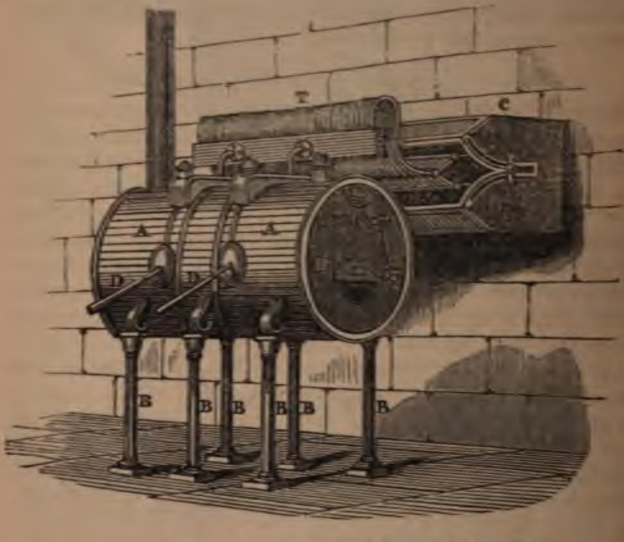


Fig. 318.—Armstrong's Hydro-electric Machine.

It consists of a cylindrical tubular boiler A A (fig. 318) of rolled iron-plate cased in wood, 7 feet 6 inches long, one foot of which is occupied by a smoke-box. The furnace and ash-hole are within the boiler, furnished with a metal screen, which is applied to exclude light during some experiments. There are 46 bent iron tubes T, in form not unlike the figure of 2, rising above the boiler, and terminating in jets formed of

partridge-wood. Either half or the whole of the jets may be opened by means of the levers which project from the sides of the boiler, D D. The boiler is insulated, and supported on stout columns of glass, B B. A zinc case C having four rows of points is placed in front of the jets; these collect the electricity from the ejected vapour. When a large quantity of electricity is required, the points are placed within a few inches of the jets; and when long sparks are needed, it is moved to a distance of about two feet. The pressure at first is about 90 lbs. This electricity is remarkable for its intensity, as well as the enormous quantity produced in comparison with other frictional machines; its quick succession of sparks causes it to inflame shavings, paper, and gunpowder.

The Electrometer.

To measure the intensity of machine electricity, there are instruments called electroscopes and electrometers. In some instances the electrical tension is so weak, that its presence can only be detected by those delicate instruments. They shew when a body is in a state of electrical tension, and whether the free electricity it possesses be positive or negative; acting thus according to the universal law of electrical polarity, their excellence depends on having a good conductor in connexion with some light bodies that may be mutually attracted or repelled with great facility.

Cavallo's electrometer consists of two balls of cork or pith suspended in a covered glass jar to two very fine wires, which are attached above to a conductor. Volta used fine straws in place of wires.

Bennett's gold-leaf electrometer is constructed on the same principle, but in place of the wires and balls he uses two fine strips of gold-leaf.

A. C. De Coulomb was the first who invented the method of measuring the quantity of action in electricity. The instrument he invented for the purpose was the torsion-balance, a needle hanging from a silk fibre in which the force of torsion or turning necessary to produce a given effect serves to measure the amount of attraction. Coulomb's torsion-balance, when fitted up for electrical purposes, consists of a horizontal needle *c* (fig. 319), made of shell-lac, having a gilded pith-ball at one end, and a counterpoise at the other; this is suspended by a

silk thread or spun glass a attached to the screw b, and can be twisted round its axis. At the zero-point of the graduated scale, a copper wire d with a ball enters through the glass cylinder: this wire is also provided with a pith-ball, gilded, and of the same size as the other: both balls touch when the torsion-needle is in a state of equilibrium, or they may be brought into contact by turning the screw b. The ball d being applied to the prime conductor of a machine affects the pith-balls below, causing them to repel each other, and thus deflecting the needle. The scale is marked on the circumference of the glass.

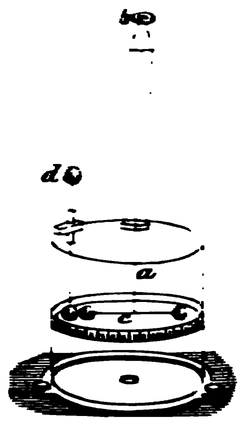


Fig. 319.

Henley's quadrant electrometer (fig. 320) serves also to measure the repulsive force of powerful electrical tensions, and is considered a necessary part of an electrical machine, being placed in a small hole made in the conductor. It consists of a graduated half-circle fixed to a conducting rod: from the centre of the circle proceeds a short reed on a fine axis, and having at its end a pith-ball. The movement of the reed, from the ball of the conductor against which it rests, up the scale marks the amount of electricity.

Fig. 320.

The Electrophorus.

An instrument invented by Volta, and known as the electrophorus (fig. 321), consists of a circular metal plate having a rim about a quarter of an inch deep at the edge, into which is poured equal parts of melted shell-lac, Venice turpentine, and resin: and a metal cover with a glass handle. The resinous plate is held in a slanting direction, and struck sharply several times with dry warm fur or flannel: the cover is then placed on the plate, and on applying to it a metallic knob or the knuckle, it is found to have accumulated a weak charge of negative electricity. Remove

the cover, and then approach the knuckle, a strong spark of positive electricity will be drawn. This may be repeated several times without again exciting the resinous cake,—indeed, under particular circumstances, such as a dry state of the air, for weeks afterwards. The electricity of the moveable plate is in this case derived not in the way of charge from the resin, but is the result of the process of induction. The upper surface of the cover is negatively, and the lower positively electrified, by induction, while touching the resin. The resinous electricity is drawn off in the first spark, leaving the positive in excess. This is drawn in the second spark, on removing the plate.

Fig. 321.

Faraday used an electrophorus of shell-lac about an inch in diameter, and seven inches in length, fixed in a wooden stand, the shell-lac being concave at the top to hold a brass ball; from this he demonstrated that inductive action, taking place invariably through the intermediate matter, would be found to be exerted, not in the direction of straight lines only, but also in curved lines. The upper part of the stick of shell-lac was excited by friction with warm flannel, a brass ball suspended by silk was placed in the hollow at the top, and the whole arrangement examined by the carrier ball and an electrometer. For this purpose the carrier was applied to various parts of the ball, the two were uninsulated whilst in contact or in position, then insulated, separated, and the charge of the carrier examined as to its nature and force. Whatever general state the carrier acquired in any place where it was first uninsulated, and then insulated, it retained on removal from that place, and the distribution of the force upon the surface of the

Fig. 322.

inducteous body while under the influence of the *inductric* was ascertained. The charges taken from the ball in this its uninsulated state were always vitreous, or of the contrary character to the electricity of the lac. When the contact was made at the under part of the ball *d* (fig. 322), the measured degree of force was 512 degrees, when in a line with its equator *c* 270 degrees, and when on the top of the ball *b* 130 degrees. Even in the position *e* the proof ball became inducteous, and at *a* it was affected in the highest degree, and gave a result above 1000 degrees.

The Leyden Jar.

The fluid, or force of electricity, seems not to spread through the entire body of the thing that receives it, but to remain on the surface. To prove this, in 1837 Faraday had a large chamber made coated with leaf-gold, and properly insulated; to this electricity was applied until sparks and pencils of light were thrown off. The philosopher then placed himself inside with candles and the most delicate electrometers, but within the chamber not the least effect was perceptible.

Smeaton, the celebrated engineer, covered a sheet of glass on both sides with thin metal, leaving a margin all around; then having applied electricity to one of the surfaces, he touched each side at the same time, and received a shock. Sir W. Watson, who had thrown great light on the subject, covered a jar on both sides with thin leaf-metal, leaving a portion near the neck bare; and this soon led to what is now known by the name of the Leyden jar (fig. 323).

Fig. 323.

A cylindrical glass jar is covered with tinfoil both inside and outside to within a few inches of the top, the uncoated glass forming the insulating part. The lid is made of baked wood, and inserted with sealing-wax; and a light metallic charging rod extends about three inches out of the lid, terminates in a knob, and is in contact with the inside coating of the jar at the bottom.

The Leyden jar is a machine for storing up electricity,

which is contained in the inner plate of metal, and balanced against electricity of the opposite kind, produced in the outer plate (connected with the earth) through the di-electric layer of glass.

When the knob of the charging rod is placed near the conductor of the machine, sparks are emitted, which grow fainter as the jar is charged. The electricity on the outside of the jar and that of the inside are communicated to each other by means of the discharging rod, represented in the wood-cut, which consists of two bent arms of brass, having at the ends round knobs, with a joint in the centre to open or close to the required distance. The handle is of glass, that it may be insulated.

When it is desired to discharge the electricity of the jar, one knob of the discharging rod is brought in contact with the outer covering, and the other to the knob of the charging rod, when the negative and positive electricity rush violently to meet each other, and with a loud report and vivid light equilibrium is restored. When we recollect that the hundreds of sparks which enter the jar from the prime conductor are discharged in one, we cease to marvel at the force and brilliancy of the discharge.

As the quantity of electricity is much greater when collected in a Leyden jar than that derived at any one time from the conductor, if a charge be sent through the human frame a violent shock is felt. When a hundred or more persons join hands, and the person at each end takes hold of a chain or other means of communication, so instantaneously is the shock felt by all, that the unanimous shout of "Oh!" is in excellent time. The shock can be communicated at almost any distance without a perceptible difference of time.

The electricity that passes into the jar is vitreous, or positive, if taken from the prime conductor; that from the cushion resinous, or negative; but whichever electricity is passed into the jar, the opposite will be induced on the outside of the jar.

If a Leyden jar be *insulated*, that is, placed so that it shall have no communication with the ground, it will be incapable of receiving a charge of any considerable amount. Let *a* (fig. 324) be a Leyden jar standing upon a glass support *b*; it will receive no charge from the prime conductor, unless a conducting communication be made with its outside coating and

the earth. But if an insulated second jar be placed at *c*, the electricity which passes off from the outside coating of *a* will charge *c*, and for every spark which passes from the prime conductor to *a* a similar one will pass from *a* to *c*.

Fig. 324.

It is therefore seen, that as vitreous electricity is communicated to the interior coating, it will be necessary to remove the same quantity from the exterior, or this would otherwise counteract the resinous electricity by which the charge is sustained. This can only be effected by placing the outer surface in connexion with the earth, the hand of the operator, or the coating of another jar.

By placing together several coated jars, uniting their charging rods, and connecting their outer surfaces by a proper base or by chains, when charged they act as one jar; a combination which is called an *electrical battery*. M. Marum formed a battery of one hundred jars, each thirteen inches in diameter, and two feet high, the whole consisting of about 550 square feet of coated glass. After charging this tremendous battery, he passed the electricity through steel bars nine inches long, half an inch wide, and one-twelfth of an inch thick, which rendered the bars intensely magnetic. The hardest wood was rent to pieces, iron wire was dispersed in red-hot balls, and tin wire became a cloud of blue smoke, which rained down hot globules. Such a discharge destroyed a dog instantly when passed through the head and spine.

Effects of Electric Discharge.

When these large quantities of electricity are used to act upon inorganic bodies, the conductors are so arranged that the body subjected to the influence may form part of a circuit. For this purpose an instrument is contrived, called a *universal discharger*.

This consists of two rods fixed on pillars of glass, having universal joints, the rods being so placed in the sockets as to be lengthened or shortened. In the centre is an insulating table on a glass rod, with a contrivance for lowering or heightening it. The circuit is completed by the rods being connected with the negative and positive portions of the battery; and the object to be acted on is placed in the centre of the little table between the ends of the rods.

Fig. 325.

A charge from a battery fired through many sheets of paper will cause a round hole through all, and produce a smell similar to phosphorus. In this experiment, if the paper be examined, a blur on both sides will be seen, evidencing that the two electrical currents have passed in opposite directions.

A leaf of gold placed between pieces of common window-glass will be so forced into them, as to change the body colour of the glass into a purple.

If a small phial half-full of salad oil have a slight piece of wire passed through the cork and so bent within the phial as to touch the glass just below the surface of the oil, and a spark be taken from a charged conductor, while a thumb is placed opposite to the point of the wire, the electricity will make a hole in the phial in its journey to the thumb. A thousand exceedingly small and perfectly round holes may thus be formed.

If, when the machine is at work, a pointed brass wire about six inches long, having a small brass ball *o* (fig. 326) at its extremity, and the other end connected with the extremity of a prime conductor, be directed against the flame of a candle *b*, the flame will be blown away as if wind from a bellows had been used.

Fig. 326.

A gold ground is sometimes given to paper or silk by first cutting out in slight card-board the pattern wished; this being placed on the silk or paper, gold-leaf is laid over the

de Physique,' of "thunder and lightning being in the hands of nature what electricity is in ours." In 1749, Franklin suggested the idea of explaining the phenomena of thunder-gusts and of the aurora borealis upon electrical principles; and in the same year he conceived the bold idea of testing the truth of his doctrine, by actually drawing down lightning by means of sharp-pointed iron rods raised into the region of the clouds. During the building of a church at Philadelphia, while waiting for the erection of the spire to try the experiment, he became tired of the delay, and conceived he might accomplish his object by means of a common kite. Accordingly, in the summer of 1752, he prepared one by fastening two cross-sticks to a silk handkerchief, which would not suffer so much from rain as paper. In the upright stick was affixed an iron point. The string was of hemp, except the lower end, which was silk. Where the hempen string terminated a key was fastened. With this apparatus, on the appearance of a thunder-storm, he went out on a common, accompanied by his son. He placed himself under a shed to avoid the rain, his kite was raised, a thunder-cloud passed over it, and no sign of electricity appeared. His heart now misgave him that the fate of his theory was sealed; but when despairing of success, suddenly he observed some of the loose fibres of the string move to an upright position, repelling each other. He now presented his knuckle to the key, and received a strong spark. Rain having now fallen, the conducting power of the string became increased, repeated sparks were drawn from the key, a phial was charged, a shock was given, and other confirmatory experiments were performed.

The identity of lightning and electricity had been proved a short time before Franklin's celebrated kite experiment, by a French philosopher, who obtained sparks from an elevated and insulated pointed rod erected near Paris; however, it was Franklin who suggested the plan.

M. de Romas, of Nerac in France, on the 7th of June, 1753, repeated the kite experiment of Franklin; he raised the kite to a height of 550 feet, and had a copper wire wound round the string, which was attached to an insulated iron tube. The flashes were extraordinary in size, and the people near felt a peculiar sensation as of spiders' webs spread over their faces. A roaring sound was heard, and straws were attracted

and repelled from the string, while the kite appeared surrounded by a bright light.

These experiments aroused the attention of philosophers in all parts of the world. But a fatal warning of the danger of trifling with thunder-clouds was given by the death of Professor Richmann, of St. Petersburg, on the 26th of August, 1753. He had constructed an instrument which he called an *electrical gnomon*, to measure the strength of electricity, and was observing the effect of a thunder-cloud on this instrument, accompanied by M. Solokow, an engraver. Professor Richmann was standing with his head inclined towards the gnomon, when M. Solokow, who was close to him, observed, as he expressed it, "a globe of blue fire as large as his fist," dart from the rod of the gnomon towards the Professor's head, which was about a foot distant. This flash caused the instantaneous death of the Professor, and M. Solokow was so much stunned that he could give no particular account of the effects upon himself.

The electricity of the atmosphere, like that of the ocean, appears to be in a constant state of commotion, being at full tide just after the rising and setting of the sun, and lowest at noon and midnight. It is generally positive, but during humid weather, storms, and under the influence of certain clouds, it becomes negative. During rain, snow, sleet, hail, thunder, and fogs, it varies rapidly from one condition to another.

Lightning is produced by the clouds becoming overcharged with electricity, and making sudden efforts to restore their equilibrium. The roll of thunder that we hear is in many cases an echo, similar to that which is heard when a gun is fired at sea and a cloud is hovering near.

Professor Thomson, in his 'Outlines of the Source of Heat and Electricity,' says, "In thunder-storms the discharges usually take place between two strata of clouds, very seldom between the clouds and the earth; but that they are sometimes also between clouds and the earth cannot be doubted. These discharges sometimes take place without any noise. In that case the flashes are very bright; but they are single flashes, passing visibly from one cloud to another, and confined usually to a single quarter of the heavens. When they are accompanied by the noise we call thunder, a number of simul-

taneous flashes of different colours, and constituting an interrupted zigzag line, may generally be observed stretching to an extent of several miles. These seem to be occasioned by a number of successive or almost simultaneous discharges from one cloud to another, these intermediate clouds serving as intermediate conductors, or stepping stones for the electric fluid. It is these simultaneous discharges which occasion the rattling noise which we call thunder." When no noise is heard, it is the distance alone that prevents it; for there can be no lightning without thunder, any more than we can take a spark from an electric machine without a snapping noise.

Often, most especially in summer, will large drops of rain fall with such force to the ground as is inconsistent with the idea of its being merely the result of gravity. The fact is, those globules of rain are like the little pith-balls before mentioned charged with electricity, which are repelled from the clouds and attracted to the earth.

The greatest security during a thunder-storm may be obtained, if out of doors, by taking shelter under sheds, carts, low buildings, or the arch of a bridge; the distance of twenty or thirty feet from tall trees or houses should be chosen, for should a discharge take place, elevated bodies are most likely to receive it. If the explosion follows the flash with great rapidity, it is evident that the electric clouds are near at hand, and a recumbent posture on the ground is the most secure. Avoid water, for it is a good conductor; and a man standing near a lake is not unlikely to determine the direction of the discharge. Within doors we are tolerably safe in the middle of a carpeted room, or standing on a double hearth-rug. The chimney should be avoided; gilt mouldings and bell-wires are equally dangerous. In bed we are quite safe; blankets and feathers being bad conductors, we are to a certain extent insulated. It is injudicious to take refuge in a cellar, because the discharge is often from the earth to a cloud, and buildings sometimes sustain the greatest injury in the basement stories.

The thunder-house (fig. 327) is an amusing illustration of the use of a continuous conductor for carrying away the lightning. Franklin first proposed the erection of a lightning conductor for the protection of tall buildings, consisting of a metallic rod in perfect communication with the earth. A is intended to represent a board shaped like the gable end of a

house, a piece of dry mahogany having been selected for the purpose, with B, a copper wire, having a brass knob at the top, which terminates at D, but is made to come in close contact and pass on to C. The central portion D is so arranged with the wire fixed to it, that it can be taken out and placed crosswise. Arrange it now as in the cut, and then attach a piece of brass chain to the hook at C, bring this in contact with the outside of a Leyden jar charged with electricity, and then with the discharging rod, send the charge from the jar to the brass knob; it will be seen that the charge will pass down without doing any perceptible injury. Now place the square piece of wood D crosswise, so that the line of continuity may be broken in the copper wire, and again send another charge of electricity to the brass knob. The shock will now throw out the piece of wood with great violence; forming a humble imitation of the effects of a stroke of lightning, the passage of which, when uninterrupted, passes quietly down, but when impeded, deals destruction around.

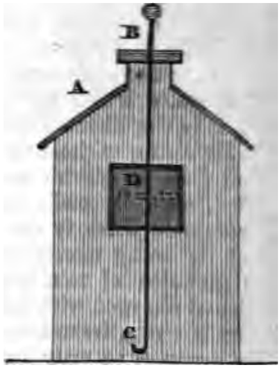


Fig. 327.

The late Mr. Crosse, so well-known for his researches in this branch of science, was in the habit of collecting the electricity of the atmosphere by means of wires supported and insulated on poles fixed on some of the tallest trees in his garden. The wires were insulated on the poles by means of a funnel, represented in fig. 328. It was made of copper, about four inches in diameter and eleven inches in length; into a cavity or socket of about two inches deep, formed at the end of the closed funnel, was firmly cemented a stout glass rod of sufficient length to reach to the open end of the funnel, where were mounted, by means of strong cement, a metallic cap and staple. The latter received the hook of a strong wire which passed through a circular plate of copper placed about four inches from the mouth of the funnel, and terminated in a hook on which one end of the exploring wire was fixed.

funnels were easily raised to the tops of trees or poles
n arrangement of pulleys. They were then taken, by
ıs of conducting wires, to a battery placed inside the
., consisting of fifty jars. In this way Mr. Crosse fre-
tly collected sufficient electricity to charge and discharge
battery twenty times in a minute, with
rts as loud as those from a good-sized
on. When the middle of the thunder-
l was over-head, he was often enabled
se into red-hot balls 30 feet of iron wire
ne length, and $\frac{1}{270}$th of an inch in
ıeter; and a crashing stream of dis-
ges took place between his large brass
, the effect of which, he says, "must be
essed to be conceived possible."

Fig. 328.

; is curiously illustrative of the economy
ıture, that the sharp points of the vege-
e kingdom are more powerfully attractive
ectricity than the sharpest point of metal
can be made by man's ingenuity; for if
ece of pointed iron and a blade of grass
eld near to a prime conductor, so that
point becomes luminous, and then
ually be drawn back, the iron will lose
uminosity long before the point of the
s. The sensitiveness of the point of
ade of grass may be seen in any part of an apartment
re electricity is being evolved. Instances have been ob-
ed in green-houses where two pointed-leaved plants have
red another plant and drawn from the air all the adjacent
tricity, by which the more humble and less prickly plant
he shade has perished, solely from want of this vital prin-
:. This is another instance of the singularly careful
ngement of the entire mechanism of nature.

he aurora borealis or northern light, that so magnificently
nines the Polar heavens, is admitted without hesitation to
n electrical phenomenon, as electricians can most success-
y imitate it on a small scale. It probably consists in the
ing of electricity through a rarefied atmosphere at some
ht from the earth's surface. Poor Franklin found, from ob-
ations made at the north pole, that the aurora was at a less

acts upon them unequally, an electrical condition is produced, one becoming positive, the other negative. Upon this depends the production of voltaic electricity.

Swammerdam, who devoted himself to the anatomy of insects, in 1678, two years previously to his death, exhibited before the Grand Duke of Tuscany an experiment, showing the contraction of a muscle by bringing a nerve connected with it in contact with a silver and copper wire. The sensation and peculiar saline taste that results from placing on the tongue a piece of silver, and under it a piece of lead or zinc, whenever the edges of the metals are brought into contact, was described in a work by Sulzer, entitled the 'General Theory of Pleasure,' published in 1767.

These circumstances, however, did not at the time lead to further investigation. To the famous Galvani, Professor of Anatomy in the University of Bologna, is due all the merit of the great discovery to which the researches of his predecessors might have led.

Arago writes, "It may be proved that the immortal discovery of the galvanic pile arose in the most immediate and direct manner, from a slight cold with which a Bolognese lady was attacked in 1790, and for which her physician prescribed the use of frog-broth." The 'Encyclopædia Britannica' states, "When one of Galvani's pupils was using an electrical machine, a number of frogs were lying skinned on an adjoining table for the purpose of cookery. The machine being in action, the young man happened to touch with a scalpel the nerve of a leg of one of the frogs, when, to his great surprise, the leg was thrown into violent convulsions." Dr. Lardner, after giving the usually-received account of Galvani's discovery, writes, "This was the first, but not the only or chief part played by *chance* in this great discovery. Galvani was not familiar with electricity; luckily for the progress of science, he was more an anatomist than an electrician, and beheld with sentiments of unmixed wonder the manifestation of what he believed to be a new principle in the animal economy; and fired with the notion of bringing to light the proximate cause of vitality, engaged with ardent enthusiasm in a course of experiments on the effects of electricity on the animal system. It is rarely that an example is found of the progress of science being favoured by the ignorance of its professors. *Chance* now again

came upon the stage. In the course of his researches he had occasion to separate the legs, thighs, and lower part of the body of the frog from the remainder, so as to lay bare the lumbar nerves. Having the members of several frogs thus dissected, he passed copper hooks through part of the dorsal column which remained above the junction of the thighs, for the convenience of hanging them up till they might be required for the purpose of experiment. In this manner he happened to suspend several upon the iron balcony in front of his laboratory, when, to his inexpressible astonishment, the limbs were thrown into strong convulsions. No electrical machine was now present to exert any influence."

How satisfactorily circumstantial are the particulars given in relation to the great discovery, and worthy the importance of the subject! The frog-broth and pupil with his scalpel form admirable subjects for the artist's pencil; they are romantic details that cling to the imagination. Then how enviable to laborious genius, that, instead of days and nights of study, years of experiments, varying in success and disappointment, yet filled with hope from occasional glimmerings of truth, and a firm conviction lending energy to perseverance,—that *chance* should save all, and present at once a fact to immortalize the observer! This is a lesson of modern times that should render us cautious of all history, as the entire account is a fable. Galvani was long and ardently a student in electrical science; so devoted was he to the subject, so absorbed in the discovery of its mysteries, that self was forgotten, and in his enthusiasm, in 1786, he grasped in his hands the rod of an insulated atmospheric conductor at the very time when lightning was darting from the clouds directly over his head. Fortunately for science and for himself, the rash and daring experiment was unattended by a fatal result.

It is on record that, twenty years before the publication of his 'Commentary,' Galvani was engaged in experiments on electricity, and that he used the nerves of a frog from finding them the most delicate test even of atmospheric electricity.

Dr. Wilkinson, of Bath, in his 'Elements of Galvanism,' published in 1804, proved this discovery of Galvani to be correct; and he calculated that the irritable muscles of a frog's leg were no less than 56,000 times more delicate as a test of [elec]tricity than the most sensitive condensing electrometer.

He found that two pieces of zinc and silver, each presenting a superficial surface of $\frac{1}{100}$ inch, produced violent contractions in the leg of a prepared frog; whilst two circular plates of zinc and copper required to be brought twenty times in contact with the condenser before any sensible divergence of the gold leaves of an electrometer was produced. By comparing the area of these plates, multiplied by the number of contacts, with the superficial surface of the minute pieces of zinc and silver employed to affect the frog's leg, he arrived at the above conclusion.

Professor Matteucci has fully corroborated this experiment, and availed himself of it by constructing a *frog galvanoscope*.

In the collection of Galvani's works, recently published by the Academy of Sciences of Bologna, his 'Experiments on the Electricity of Metals' are dated September 20, 1786. His other scientific essays on his various discoveries are numerous. It was not until the year 1791 that the discovery of what is termed galvanism was published to the world by its author.

Galvani showed that if a metallic arc be constructed of two different metals joined together, and one extremity of it touched the nerves and the other the muscles of a frog, a contraction or convulsion took place; that the metals used should be those least liable to oxidation; and that in the experiments the electrical machine was unnecessary.

The Voltaic Battery.

The announcement of the discoveries by Galvani aroused the attention of scientific men all over the world, who repeated the experiments of the Bolognese philosopher. Amongst others was Volta, who for thirty years occupied the chair of Natural Philosophy in the University of Pavia, and whom Napoleon did himself the honour to create a count and senator. Volta combated the opinions of Galvani as to the different parts of an animal being in opposite states of electricity, which the application of the metallic arc restored to an equilibrium. He considered that the metallic arc developed electricity which irritated the nerves, sometimes producing the sensation of light or taste, sometimes exciting contractions. In August 1796 he discovered that which has rendered his name immortal, the Voltaic Pile, a description of which was published in 1800, in the 'Philosophical Transactions.' It consists of alternate

layers of silver or copper and zinc plates arranged in regular order, one above another, with moistened flannel or pasteboard between each pair. By wetting the flannel or pasteboard with salt and water, the strength of the shock, which is felt on moistening the fingers and touching each end, is increased.

De Luc formed what is called an electric column, or dry pile; this consisted of small round pins of silver, zinc, and paper, placed alternately. About a thousand of these being inserted in a dry glass tube, a brass cap at each end screws them up tight. The centre of the pile is neutral, but the ends are in opposite electrical conditions. The late Mr. Seiger improved upon this by placing together about twenty thousand series of silver, zinc, and double discs of writing-paper; from this bright sparks could be produced, thin wire melted, and shocks received.

Many valuable and important improvements in the construction of the apparatus for generating voltaic power have been made by Cruickshank, Wollaston, Daniell, Smee, Grove, and Bunsen, but the details would occupy too much space to describe.

The general principle of Cruickshank's battery, however, consists in having a wooden trough lined with pitch, into grooves of which, cut in the sides, are placed in an upright position metallic plates of zinc and copper, and alternately, of any dimensions,—and between each division is poured an exciting liquid consisting of diluted acid. The copper plate of one cell is connected by a wire with the zinc plate of the next, in all voltaic batteries. From each end proceeds a wire, which

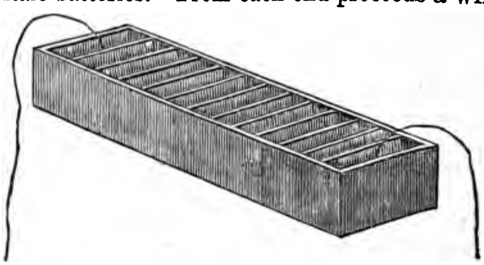


Fig. 330.

from the zinc end of the trough conducts positive, from the copper end negative electricity (fig. 330).

Frictional or machine electricity is remarkable for *intensity*; that is to say, it has great power in overcoming obstacles, and restores its equilibrium with a vivid spark. To produce a large spark, a very large voltaic battery is needed. However, in *quantity*, the voltaic form of electricity far excels the other. The term quantity signifies the power of causing chemical change or decomposition. This is exerted to a very small extent by the electrical machine, but most powerfully by the voltaic battery. Another difference between the frictional and voltaic electricities is found in the *continuous* action in the latter. The terminations of the wires form the *poles* of the battery; as soon as they are brought in contact, a slight spark restores electric equilibrium for the moment, but this is immediately disturbed by the continuance of the chemical action in the cells, so that spark follows spark apparently without intermission. This continuous action, so unlike the momentary discharge of the friction-machine, is called *the current*. It may produce a notable effect without possessing a sufficient intensity to cause a visible spark.

It is found by experience that the *intensity* of the electric force is not increased by enlarging the size of the plates; which, however, adds to the *quantity* of electricity excited. Thus, a few large plates are used to effect chemical decomposition, and a number of small plates to produce a spark, electric shock, &c.

Wollaston's voltaic battery (fig. 331) consists principally in the arrangement of doubling the copper plates *c c c*, so as to expose them to both surfaces of the zinc *b b b*. The plates are screwed to a bar of wood *a*; pieces of wood or cork are placed between the zinc and copper surfaces to prevent their contact; they are then placed in a trough.

Fig. 331.

To keep the battery in perfect action, it will be necessary from time to time to cleanse the zinc plates from the oxide which accumulates upon their surfaces; brushing them over with a little muriatic acid or nitrate of mercury will

answer the purpose best, and secure a greater permanency of action. The common voltaic pile, on account of the loss of moisture, generally loses its electrical action in a few days, and this cannot be renewed without the trouble of reconstruction; but by Wollaston's contrivance, which becomes active on merely filling the cells with the proper acid or saline fluid, much trouble and time is saved.

Mr. Grove's batteries are constructed out of a stoneware porous vessel divided into partitions, into each of which two zinc plates, with a sheet of platinum between them, are placed, and connected together with clamp screws. Common rolled zinc, one-thirtieth of an inch thick and well-amalgamated with nitrate of mercury, may be employed. On the zinc side, or into the porous vessels, is poured a solution of either muriatic acid, diluted with from two to two and a half water; or, if the battery be intended to remain a long time in action, of sulphuric acid, diluted with four or five parts of water; and on the platinum side, concentrated nitro-sulphuric acid, formed by previous mixture of equal measures of the two acids. The apparatus should be provided with a cover containing lime, to absorb the nitrous vapour.

Fig. 332.

The accompanying figure (332) represents the complete battery, with one set of plates removed from the porcelain trough *d*, showing the arrangement: *a* is the bent zinc plate, *b* the insulated platinum plate in its porous cell, *c* the next platinum plate, connected by means of a binding screw with the zinc at *a*.

Many curious and abstruse questions may be raised with

respect to the theory and action of the voltaic battery. It is not our intention to enter into these. We proceed to glance at its more important practical applications, some account of which may claim a place even in an elementary work.

Electrolysis, or Voltaic Decomposition.

It has been shown experimentally by Faraday and others, that voltaic electricity *immeasurably* surpasses that of the glass machine in its power of causing chemical decomposition. Thus an amount of friction-electricity, sufficient, when discharged, to kill a small animal, had to be multiplied 800,000 times before it would decompose a single drop of water.

Chemical decomposition produced by the voltaic battery is called electrolysis. Its amount has a relation to the size of the plates in the battery, and the amount of chemical action going on in the cell. The substance must be in the liquid state, or dissolved in a liquid, before it can be decomposed by passing the galvanic current through it. The particles must be capable of ready motion and transference. The decomposed compound is arranged into two parts, one of which is collected, or evolved (if a gas), at one pole of the magnet, the other at the other. This takes place in a decomposing cell where are the two poles of the battery, which may terminate in two metal (platinum) plates. The one which corresponds with the zinc in the other cells is the positive pole, the one answering to the platinum the negative pole. When water is acted on, hydrogen gas bubbles up at the negative, and oxygen at the positive pole. If an alkali be decomposed, its metal appears at the same pole as the hydrogen. It was thus by means of the galvanic battery that Davy in 1807 was enabled to announce the great discovery that the alkalies were metallic oxides, an announcement that opened out a new era for chemical science. Chlorides and iodides of the metals, and metallic salts are all in this way decomposed with various facility, the metal going to the negative, the element or compound combined with it, to the positive pole of the decomposing cell.

Bodies which are capable of being thus decomposed by the voltaic current are called *electrolytes.*

The arrangement of different bodies at different ends of the wires communicating with the battery is shown in the following

simple experiment: if a glass tube bent in the form of the letter V be filled with distilled water, and corked at each end, if then two pieces of platinum wire be passed through the corks and allowed to reach within an inch or two of each other in the tube, and the other ends of the wires connected, the one with the positive and the other at the negative end of the battery, a continued stream of bubbles of gas will proceed from the negative wire to the end of the tube, and will be found to be hydrogen or inflammable gas, and that from the positive wire will accumulate at the other end of the tube and be pure oxygen.

From Davy's paper in the 'Philosophical Transactions,' on "Some Chemical Agencies of Electricity," we quote the following interesting experiment on the passage of acids, alkalies, &c., by the influence of the electric current, through solutions of other substances.

"An arrangement was made, consisting of three vessels (fig. 333) containing as many different fluids; a solution of sulphate

Fig. 333.

of potash was placed in contact with the negatively electrified point N, pure water was placed in contact with the positively electrified point P, and a weak solution of ammonia was made the middle link of the conducting chain, so that no sulphuric acid could pass to the positive point in the distilled water without passing through the solution of ammonia; the three glasses were connected together by pieces of amianthus. A power of 150 pairs was used; in less than five minutes it was found, by means of litmus-paper, that acid was collecting round the positive point; in half an hour the result was sufficiently distinct for accurate examination.

"The water was sour to the taste and precipitated a solution of nitrate of barytes.

"Similar experiments were made with solution of lime and

weak solutions of potash and soda, in place of the ammonia, and the results were analogous. With strong solutions of potash and soda a much longer time was required for the exhibition of the acid; but even with the most saturated alkaline lixivium, it always appeared in a certain period. Muriatic acid from muriate of soda, and nitric acid from nitrate of potash, were transmitted through concentrated alkaline menstrua under similar circumstances. When distilled water was placed in the negative part of the circuit, and a solution of sulphuric, muriatic, or nitric acid in the middle, and any neutral salt, with a base of lime, soda, potash, ammonia, or magnesia, in the positive part, the alkaline matter was transmitted through the acid matter to the negative surface, with similar circumstances to those occurring during the passage of the acid through alkaline menstrua; and the less concentrated the solution, the greater seemed to be the faculty of transmission."

These and similar experiments excited, when first promulgated, the utmost astonishment in the scientific world.

Ozone.

During the decomposition of the water by the voltaic current, a powerful phosphorous-like odour is evolved, which has received the name of *ozone*. The evolution of this matter, an allotropic form of oxygen, although long recognized during the action of the common electrical machine by its odour, the cause of the formation of this peculiar body was only lately traced by Professor Schönbein of Bâle. The substance is evolved under many other circumstances, as when a stick of phosphorus is allowed to remain for a short time in a large glass bottle full of moist air; or still better, by placing a little ether in a large glass bottle, and then holding in it a previously heated glass rod, so as to reach nearly to the surface of the ether. Ozone is a most energetic ozidizing agent: a piece of silver leaf, on being exposed to its influence, crumbles almost immediately into oxide; it is also a most remarkable deodorizer, almost instantly removing the offensive smell evolved by a piece of tainted meat. Ozone frequently exists in the atmosphere, especially in the air blowing from the sea, and, in all probability, plays a most important part in the laboratory of nature. It acts on iodide of potassium, like chlorine, setting

free the iodine; hence a piece of paper, moistened with a mixed solution of iodide of potassium and starch, turns blue when exposed to its influence, and thus becomes a delicate test of its presence in the atmosphere. Various kinds of apparatus called *ozonometers*, have been constructed for the purpose of measuring the quantity of ozone in the atmosphere, in relation to questions of health and disease.

The Coil Machine.

That the voltaic current is capable of causing the contraction of the muscular tissues of animals under certain circumstances, was discovered from the first by Galvani. Contractions may be caused in the limb of a paralytic patient by the current of an ordinary battery. But to cause a *shock*, or powerful impression, the intensity of the galvanic electricity must be in some manner augmented. This may be effected by causing it to pass along a considerable length of wire around a magnet in the centre.

The *Electro-magnetic Coil Machine* is used as a remedial agent in the treatment of many forms of chronic disease. A weak current must in all be begun with, and gradually increased in strength as the patient ceases to be affected by it; the best form for administering the galvanism is by the agency of such a combination, as is here represented (fig. 334).

Fig. 334.—Electro-magnetic Coil Machine.

From *the battery*, an upright jar in which plates of zinc are immersed in diluted sulphuric acid, proceed two copper wires, which are connected by two binding screws to the magnetic

coil. This is made by winding round a hollow cylinder of wood a considerable length of stout copper wire, covered with cotton thread for the purpose of insulation; over this coil a much greater length of fine copper wire, previously covered with cotton, is wound. The two ends of the wire are then firmly connected with the two binding screws in front of the apparatus. The coil of thick wire is called the *primary*; through it the current from the battery first circulates. The coil of thin wire, termed the *secondary*, is intended to convey to the patient the electricity which is developed in it by induction every time contact between the primary coil and battery is broken and renewed. The breaking and renewing of the battery contact is effected by a little electro-magnet, with a vibrating armature, placed on the top of the small stage, through which the current from the battery is caused to pass at very short intervals. The vibrating motion of the armature throws on and cuts off the electric current from the coil, and a rapid series of shocks may thus be communicated to a patient, being directed through any part of his body by means of the sponge directors shown lying loose in the figure.

Ruhmkorff's Apparatus.

M. Ruhmkorff, a philosophical instrument-maker at Paris, has contrived, by the application of well-known principles, and by a new combination and enlargement of the induction coil, to produce from voltaic electricity some of the most beautiful effects of the electric current excited by a very powerful machine, and thus to show most clearly the identity of the force excited by friction and by chemical action. The apparatus consists of a primary coil of copper wire, round which there is wound a large quantity of finer covered wire; and by sending a voltaic current through the first soil, electricity is induced in the second, though no portion of the voltaic current passes through it. This "secondary current," as it is called, possesses an intensity resembling that excited by the electrical machine. Ruhmkorff's apparatus may be described in a few words, as a greatly enlarged medical coil machine. The flood of electricity developed by this apparatus is exhibited in many beautiful experiments. For a successful exhibition of the capabilities of the machine, it is requisite to employ a dark room, and to be provided with an efficient air-pump.

Experiment 1. The globe here represented, after being well exhausted of air, is attached to the apparatus as at fig. 335 (No. 1), when a beautiful faint blue light is apparent on one of the knobs and wires. Upon turning the piece A (No. 3), the light appears on the other knob and wires. In this condition unscrew the globe at B, and place it over a large bottle containing a little alcohol, spirits of turpentine or naphtha, and allow the air and vapour of the spirit to enter the globe; let these be rarefied to the utmost by having recourse to the air-pump, and again attach the globe to the apparatus, when it presents the appearance of being full of a beautiful coloured light, varying according to the spirit employed, each being stratified or in a circular form.

Experiment 2. Place, as in No. 4, two *very thin* iron wires. When these are held close to each other, as represented, light passes from one to the other. The wire from which the light passes remains *cold*, the other becomes so *hot* that its end *melts into a knob*. It appears as if all the light was emitted from one end, and the heat from the other. In thus experimenting care must be taken to hold only one wire—the cold one; it must be held close to the other. Inattention to this caution will result *in a most severe shock*.

Experiment 3. Remove the break. Attach two wires to X X (No. 5). Hold these so as, at pleasure, to complete and interrupt the galvanic circle. Other two wires are attached at P P, their ends being about $\frac{2}{3}$ of an inch asunder. When the current is closed or broken at A A, a spark passes between B and B.

Experiment 4. Having held a glass plate, 8 or 9 inches in length, over hot water, so as to cover it with vapour, place the points B B (No. 7) on the glass at 7 or 8 inches distance. On closing the circuit at A A (No. 5), a long zigzag spark, like forked lightning, passes between the points B B.

Experiment 5. Take a gilt-edged book, as represented No. 6; place the ends of the wire B B (No. 6) at the points B B (No. 5); upon closing the current at A A, the whole of the gilding of the book appears beautifully luminous.

Experiment 6. Place some *very fine* copper filings upon paper, and allow the ends of one of the wires B B (No. 2) to approach. Connect the wire A A permanently. The copper filings will be attracted from the paper by one of the wires

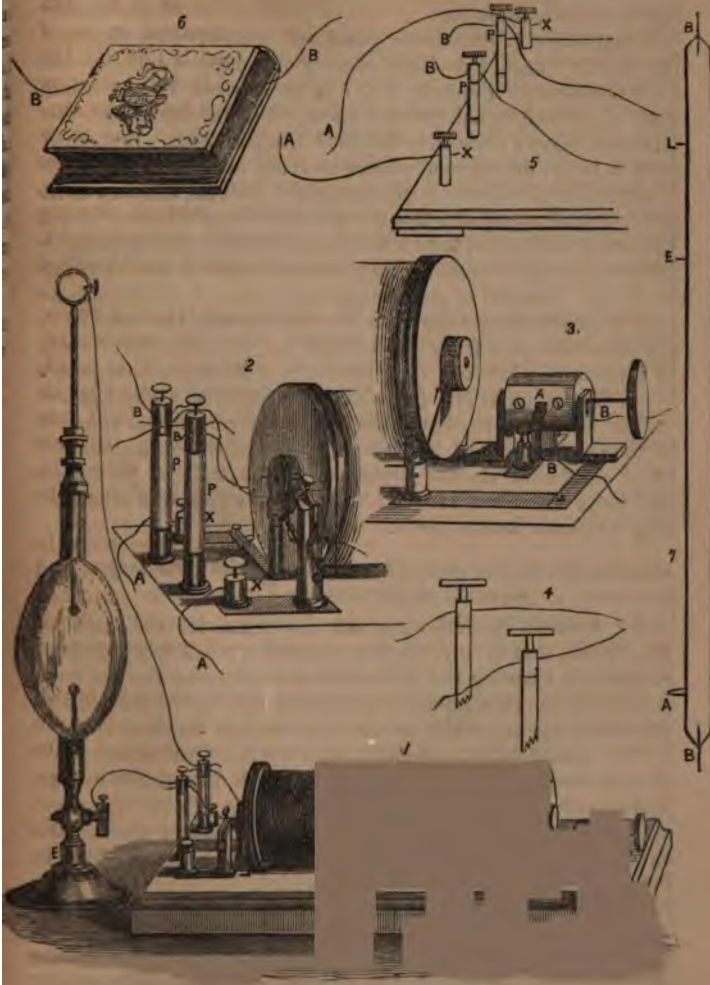


Fig. 335—Ruhmkorff's Apparatus.

B B, to a height of nearly half an inch, whilst the other wire exerts no such influence.

Experiment 7. Substitute powdered plumbago on glass for the copper filings, a decided instance of repulsion ensues.

Experiment 8. Suppose No. 7 to be a glass tube of about $\frac{1}{12}$th of an inch in calibre, and about 18 inches long, with the platinum wires B B securely fastened into both ends. Let a thin portion be drawn out as at A, and mercury introduced, as in the construction of a common thermometer. Boil the mercury until it is nearly all expelled, when the tube is to be sealed at A. In the vacuum thus obtained light will be seen to pass from one platinum wire to the other, on connecting the tube with the apparatus, as in No. 1. Instead of connecting both wires, if the lower one only is attached, and the tube be touched with the hand at L, the light will pass from the bottom up to L, but there stop. If the hand be lowered to E, the light will stay at that point.

An Englishman, Mr. Hearder of Portsmouth, a blind philosopher, succeeded about the same time Ruhmkorff was engaged in the construction of his machine, in making an instrument on a somewhat similar principle, but capable of producing still more wonderful results; the cost of which was considerably less than Ruhmkorff's.

Stratifications and Dark Bands in Electrical Discharges, as observed in Torricellian Vacuums.

Mr. Gassiot, by following out the principles indicated by Mr. Welsh, that of carefully removing all trace of moisture, and thoroughly cleaning the tubes before introducing the mercury, succeeded in obtaining Torricellian vacuums which exhibit stratifications in a uniform and very marked manner.

The sealed tubes generally used by Mr. Gassiot are made of the usual glass tubing, about an inch internal diameter, and varying from 10 to 38 inches in length. In the latter case the platinum wires are about 32 inches apart. One of the tubes made by Mr. Ladd for Mr. Gassiot is 5 feet 3 inches in length, with wires 4 feet 9 inches apart.

With a tube prepared on Mr. Welsh's principle, and the usual sized Ruhmkorff's induction-coil excited by a single cell of Grove's nitric acid battery, with or without a condenser, the phenomena of the stratified discharge can be seen and examined with ease, and without the trouble and uncertain manipula-

tion of an air-pump, or the employment of phosphorous and other vapours.

If the discharges are made in one direction, a black deposit takes place on the side of the tube nearest the negative terminal. This deposit is platinum in a state of minute division emanating from the wire, which becomes black and rough as if corroded. The minute particles of platinum are deposited in a lateral direction from the negative wire, and consequently in a different manner from that described as occurring in the voltaic arc (De la Rive's 'Electricity,' vol. ii. p. 288), so that the luminous appearance of the discharge from the induction-machine can in no way arise from the emanation of particles of the metal.

A series of experiments made in the apparatus first prepared, by which the mercury is lowered or raised in the vacuum tube, gives a peculiar appearance when the mercury is made either positive or negative. In some instances, and particularly when, instead of wires, platinum balls $\frac{1}{8}$th of an inch in diameter are used for terminals, the stratifications instantly cease when the mercury rises above the negative ball; but when the pole of a magnet is presented to the positive ball, the stratifications are drawn to the length of two or three inches down the tube.

In the sealed tubes the stratified discharge is obtained by frictional electricity; and if a charged Leyden jar is discharged through the vacuum by a wet string, the stratifications are as distinct as from the induction coil.

By a single disruptive discharge of the primary current excited by a single cell, the entire tube, whatever may be its length, is filled with stratifications as far as the dark band near the negative wire. From this experiment Mr. Gassiot is of opinion that the phenomenon cannot be in any way due to the vibrations of the contact-breaker. With one, two, or three cells no appearance of a luminous discharge can be perceived on making contact; it only appears on breaking. If, however, the intensity of the primary current is increased by using ten or more cells, stratifications appear on making as well as on breaking the contact of the primary circuit. These stratifications are always concave towards the positive terminal, and as the discharges, on making and on breaking, emanate from different terminals, their concavities are in opposite direc-

tions,—a fact which explains the different ways in which several electricians have described and figured the form of the discharge with the coil. These stratifications appear in quick succession, but they can always be separated in any part of the tube by a magnet.

Under certain conditions the positive discharge assumes a peculiar form.

The peculiar difference between the positive and negative discharge, is best observed in an apparatus of which both terminals are made of surfaces of mercury, or the positive of a surface of mercury, and the negative of a wire, or the reverse. In this apparatus, also, the mercury at one end can be elongated 8 or 10 inches. When the mercury is negative, its entire surface is covered with a brilliant glow; when positive, the extreme point of the mercury exhibits intense light, but the remainder of the surface appears unaffected by the discharge. In order to test whether any signs of interference can be detected, a tube is required with four wires, by which discharges can be observed when taken from separate coils with platinum wires hermetically sealed, as in the previously described apparatus; but in no case did any sign of interference appear. The discharges, whether in the same or in opposite directions, mingle; the stratifications, having a tendency to rotate round the poles of a magnet, and obeying the well-known law of magnetic rotations, can be separated by either pole.

If, instead of sealed wires, tinfoil coatings are placed on the vacuum tube, and the coatings are attached to the terminals of the induction-apparatus, brilliant stratifications immediately appear in the portion of the vacuum between the coatings, but without any dark discharge. On approaching a powerful magnet, the stratifications divide into two equal series, in which the bands or strata are concave in opposite directions.

If a vacuum tube, with or without wires or coatings, is placed on the induction-coil, or on the prime conductor of an electrical machine, stratifications appear which are divided by the magnet. Having thus ascertained that there are two distinct forms of the stratified electrical discharge, M. Gassiot, for the sake of clearness of expression, terms them the direct and the induced discharge. The direct discharge is that which

is visible in a vacuum when taken from two wires hermetically sealed therein; this discharge has a tendency to rotate, as a whole, round the poles of a magnet. The induced discharge is that which is visible in the same vacuum when taken from two metallic coatings attached to the outside of the tube, or from one coating and one wire; this discharge is divided by the magnet, and the two divisions have a tendency to rotate in opposite directions. The character of these two forms of electrical discharge can always be determined by the magnet.

The correlation of magnetic and electric action has long since been known; but the curious effect of the power of a magnet to draw out the stratifications from the positive terminal, and in some instances its powerful action on that portion of the discharge which exhibits the phosphorescent light in its greatest intensity, are worthy of further examination. In the preceding experiments Mr. Gassiot's object was directed to the examination of the stratified and of the dark band discharge; and he is inclined to believe that the stratifications in the positive, and the dark band between it and the negative glow, although apparently similar, are effects arising from distinct causes—the former from pulsations or impulses of a force acting in a highly attenuated but resisting medium, the latter from interference.

Electrotyping Process.

By one of those singular coincidences in the history of discoveries, which have been frequently remarked, Jacobi of St. Petersburg in 1837, and Spencer of Liverpool in 1838, announced, what the former called Galvano-plastik, and the latter Electrography. Although there exists this difference of date, the discoveries were independent of each other. The art is now named electro-metallurgy, of which electro-plating is an important branch. Mr. Spencer's invention was for depositing copper on metallic surfaces, by using a slight coating of wax. M. Jacobi, in March 1840, recommended the giving, by means of plumbago, a conducting surface to non-metallic substances; but in January of the same year, Mr. Murray described the same mode in this country, and deservedly received the silver medal from the Society of Arts for a discovery of such practical importance.

The practice of electrotyping from this period took its rise:

ware containing the solution of acid and water, *d* the copper solution. The solution is first poured in, then the acid water; and finally the wire, with the mould hanging at one end, is attached to the zinc. Especial care must be taken that the shelf is kept supplied with crystals of sulphate of copper, that the quantity be not too small proportionately to the zinc, and that the concentrated part of the solution be not allowed to crystallize and remain at the bottom.

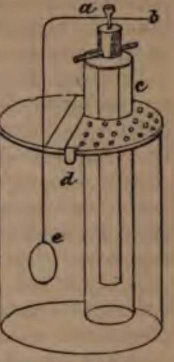


Fig. 337.

Fig. 338 is another arrangement: *a* is the battery; *b* the decomposition cell filled with the solution of sulphate of copper; *e, f* sheets of copper to furnish a supply to the moulds. In this cell the solutions are poured in, the wire *d* connecting the copper sheet and the copper of the battery, after which the wire *c* from the zinc to the moulds is fixed, and adjusted in its proper position. The charging liquid is a mixture of one part sulphuric acid, two parts saturated solution of sulphate of copper, and eight parts of water. In this arrangement, when the wires are con-

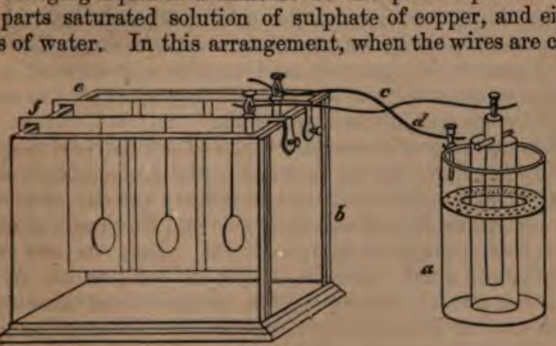


Fig. 338.

nected, the copper from the solution is deposited on the mould, and the plate of copper is gradually dissolved, thus sustaining the strength of the solution. Rather a longer time is required by this method than with the single cell; two days will generally produce a medal of very good substance, firm and pliable; the time required, however, for these experiments, depends

much on the temperature. If the solutions are kept very hot, a medal may be made in a few hours: in severe weather, the action of the battery almost ceases, and it is necessary to carry on the operations before a good fire.

Professor Jacobi of St. Petersburg invented a method of converting any line, however fine, engraved on copper, into a relief by a galvanic process; and to Jacobi and Spencer must be awarded the honour of having made one of the most important discoveries of modern times.

It would be interesting, if our space permitted, to trace the rapid development of an art which now ministers to our daily enjoyment—for in some shape or other, the results of the electrotype are ever before our eyes—but we are obliged to forbear. We cannot, however, pass on without noticing one unexpected and important sanatory result. The power which "takes a cast of the eye of a dragon-fly so perfect that under the microscope it exhibits the innumerable facets of the compound eye," and which could with as much ease cover the dome of St. Paul's with gold, if it could only be placed in an apparatus sufficiently large, has banished the old process of water-gilding, which very often produced in the operatives a miserable disease known as mercurial intoxication. The mercurial process is now only used for silvering mirrors, and it may be safely predicted that this will in a short time be superseded by one less injurious to health.

We must not omit the description of a *Platinized Graphite Battery* for electrotyping purposes. Plates of graphite of the required size, obtained from gas-retorts, are immersed in a mixture of one part of sulphuric acid and four parts of water, for at least a couple of days and nights. They are then rinsed in water and dried. A hole is then drilled in each plate to receive a rivet. The top of the plate is then varnished on either side of the rivet-hole, and on both sides of the plate. About an inch in width on both sides in the middle, having the rivet-hole in the centre, is to be left unvarnished. Electrotype copper is now to be deposited upon the part that is left unvarnished, the object being to provide a surface to which a connecting slip of copper can be soldered. A slip of copper about an inch in width is then prepared and entirely tinned. The copper that has been deposited on the graphite plate is tinned in like manner. The object of this is to preserve the copper

from the action of the acid. The slip of copper is attached to the graphite plate by means of a copper rivet, which has been previously tinned; and then by means of the soldering iron. A strong and perfect connexion is thus obtained. The plates are finally platinized. To accomplish this a mixture of one part of sulphuric acid and ten of water is prepared. Into this are dropped a few crystals of chloride of platinum, till the liquid acquires a pale straw colour. A common battery of three or four cells is now required. The graphite plate is connected with the zinc end of the battery, and a couple of platinum plates are connected with the other end. The graphite is placed between the pair of plates, and in a decomposition cell, and the solution of chloride of platinum is poured in till the graphite plate is sufficiently immersed. In twenty minutes or half an hour the surface of the graphite will be coated with fine black particles of platinum powder. The battery cells are ordinary stone jars. The zinc plates are well-amalgamated, and are placed with their foot in mercury, contained in a gutta-percha slipper. Batteries of this kind are very inexpensive, and are very economical in use.

Electro-plating and gilding are accomplished by having very carefully prepared solutions of the desired metals first made, either for a single-cell battery or a decomposing trough.

The purposes to which electro-metallurgy may be applied are innumerable. By it articles are silvered, coppered, zinced, and gilt; etching is effected; casts are taken from metal type, wood-engravings, busts, and statues; pipes are made without joints; metal lace and cloth prepared; and delicate flowers and minute insects, modelled with life-like exactness.

Explosion by Voltaic Current.

If a galvanic battery be able to heat a wire of given size and length, and the wire be drawn out to a greater length, it will heat it equally in its extended state; or, as Faraday states, "a current that will heat one inch of platinum will heat a hundred inches, allowance being made, however, for the cooling effects of the air." Thus the galvanic current may be employed to fire gunpowder at a safe distance. At the suggestion of Mr. Palmer, it was first employed in submarine operations by General Pasley, in the removal of obstructions in the Thames, and afterwards of the wreck of the 'Royal

George' at Spithead. But perhaps one of the most interesting operations effected by this power was the blasting of the Round Down Cliff at Dover, on Thursday, January 26th, 1843. We extract the following account, from the 'Illustrated London News,' of this extraordinary achievement of engineering skill.

"A small arched drift-way or tunnel, 300 feet in length, running from east to west, was pierced through the bottom of the cliff: from this, at nearly equal distances, three well-like shafts were sunk, and from these again proceeded three horizontal galleries. At the end of each gallery a chamber was prepared, with a box for the gunpowder. The centre box contained 75 barrels, and the eastern and western 55 each, making in the whole the unparalleled charge of 185 barrels, or 18,500 lbs. The gunpowder was placed in upright bags, the mouths open, and powder sprinkled very thickly between

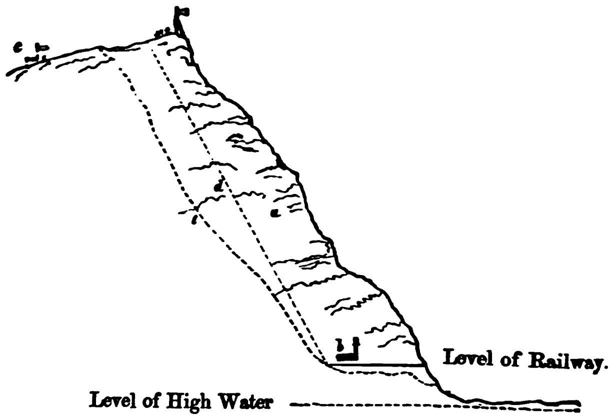


Fig. 339.—*a*. Section of Round Down Cliff. *b*. Drift-way, and chamber where the powder was placed. *c*. Battery-house. *d*. Line of required face. *e*. Face formed by the blast. Scale, 200 feet to an inch.

them. Two bursting charges were placed in each box, by which ignition in two places in each charge was produced at the same instant, and the simultaneous action of the whole charge very much facilitated. These charges were placed 70

feet from each other; the centre one (the point of greatest resistance) 90 feet, and the lateral ones 70 feet from the face of the cliff. The apparently dangerous work of packing the powder and inserting the firing-wires in the bursting-charges was completed in three hours, by Mr. Hodges, the assistant-engineer, and Corporal Rae, of her Majesty's Sappers and Miners. The chambers and contents were then carefully examined and approved by General Pasley and Lieut. Hutchinson, and the galleries and shaft closed up with tightly rammed chalk and sand. The mass to be scattered by this latent power was calculated at about 500,000 tons; but the quantity actually removed was proved to be upwards of 1,000,000 tons.

"On the slope of the cliff a wooden shed was constructed, in which was placed a triple set of immense compound batteries, each one consisting of three sets of Daniell's batteries of six

Fig. 340.—*a.* Drift-way. *b.* Shaft. *c.* Gallery. *d.* Powder-chamber. *e.* Box of powder-bags. *f f f.* Wire from batteries. Scale, 10 feet to an inch.

cylinders each, and two plate batteries of twenty plates each. From each of these batteries a wire was conducted over the cliff to a powder-chamber, where it terminated in a bifurcated

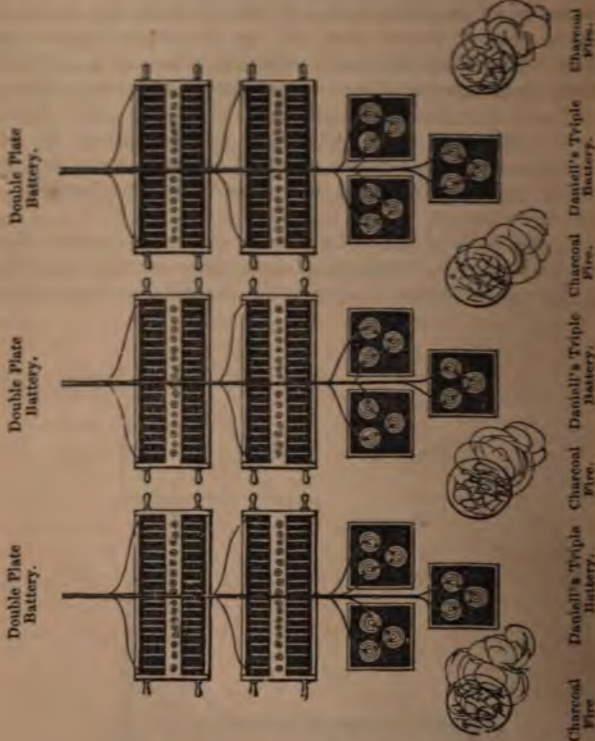


Fig. 341.—Plan of the Batteries.

point of platina, which the galvanic fluid, as it passed over them, heated to an intense white heat, sufficient to ignite the powder. These wires were composed and formed of stout copper wires placed round a rope, to which they were firmly attached by a coil of spun-yarn, and the whole again wound round and covered by well-tarred yarn. These wires were

about 2200 feet in length. Five large charcoal fires, to dissipate damp, completed the arrangements" (fig. 340).

"At precisely twenty-six minutes past two o'clock a dull, muffled, booming sound was heard, accompanied for a moment by a heavy jolting movement of the earth which caused the knees to smite. The mines were fired! In an instant the bottom of the cliff appeared to dissolve, and to form by its melting elements a hurried sea-borne stream. The superin-

Fig. 342.—Round Down Cliff from the Beach, as it appeared after the explosion.

cumbent mass, to the extent of 500 feet, was then observed to separate from the mainland, and as the dissolution of its base

was accomplished, to sink, by gradual subsidence, t·
In two minutes its descent and dispersion were a
The huge volleys of ejected chalk, as they swelle
like stream, seemed to roll inwards upon themselve
their integral blocks, and then to return to the
smaller and coalescing forms. The mass seemed to
to be splitting, whirling, fleeing, under the influ
unseen but uncontrollable power. There was no r
plosion, no bursting out of fire, and, what is very r
not a single wreath of smoke, for a mighty agent ha
work under an amount of pressure which almost m
energies; the pent-up fires were held in their intens
smoke was consumed, and when their 'dogs of
actually let loose, they were even then compelled to
spiriting gently.' A million tons of weight and a mill
of cohesion held the reins. When the turf at the top
cliff had been launched to the level of the beach, the
of *débris* had extended a distance of 1200 feet, and cov
surface of more than fifteen acres!"

Voltaic Heat and Light.

Sir Humphry Davy exemplified the intense h
derived from the voltaic battery. With a series of 2
inch plates, he produced an arched stream of light betw
charcoal points, with which he fused the most unman
of the metals with the utmost ease. Diamond vanish
carbonic acid gas; when thin leaves of gold were bu
beautiful white light tinged with blue was emitted; s
gave an emerald-green light, copper a bluish-white li
red sparks, lead a purple, zinc white tinged with re
fessor Daniell, with his improved battery, produced
powerful flame between two charcoal points, as to s
own face and inflame the eyes of the spectators. Th
cause of this light science has not yet been able to det
all that is known is, that it is produced by the disch
voltaic electricity through a non-conducting or r
medium, and its properties are much the same as those
sun's rays. Some years ago M. Archereau exhibit
electric light in Paris, and it was proposed to have
several points, whereby the city might be illuminated
sun at night. Difficulties, however, arose to prevent the

cation of the invention, arising principally from the inability to render the light continuous. Mr. Allman proposed an ingenious self-adjustment, whereby when the electricity was more than necessary, the charcoal points became wider apart; and when it decreased, they approached nearer.

In 1846, Messrs. Greener and Staite took out a patent for this mode of illuminating thoroughfares and public buildings. They proposed to use charcoal and platinum points in air-tight vessels. Mr. Staite affirmed that with a battery of 40 small cells in series, the light was equal to 380 tallow candles, 300 wax candles, or 64 cubic feet of gas; this being effected by the consumption of little more than three-quarters of a pound of zinc per hour. In 1848 it was publicly exhibited in London.

The electric light is so brilliant as to dazzle inconveniently those who are near. It diminishes rapidly in intensity, as the spectator removes from it. The opposed points are found to wear away rapidly. But the intermitting character of the light, a fault not yet quite overcome, has been hitherto fatal to the general use of this invention.

Mr. Holmes has been perfectly successful in the production of a continuous and powerful electric light, by combining a series of magnets, arranged in a circular form, and driven by a small steam-engine. His light has been for some time in operation at the South Foreland Lighthouse. Eye-witnesses describe the magnetic light, seen from the sea, as intense, like a little sun, and like that luminary it "sets" from the convexity of the earth. At 30 miles it does not appear to be the least dimmed, and it even penetrates haze and fog so as to indicate its "whereabouts." Although the light itself is only a "spark" of about a quarter of an inch long, it is too vivid to be stared at with an unprotected eye. Seen through black goggles, a beautiful cone of light may be observed falling from the upper carbon to the lower, very different in intensity to the glare of a murky coal fire, or even the luminous band of light from a reflector.

Professor Way's Electric Light.

The principle of this light is simply the application of a running stream of mercury in place of the charcoal points. The apparatus consists of an oval-shaped pair of tubes connected at each end, and a round hollow globe about the size of

an orange, in which is placed the mercury. The mercur[y] runs from a point to a cup in the centre, enclosed within [a] glass tube, and here it is heated to a white heat as it flows i[n] a fine stream from the upper ball into the cup, and thence int[o] the lower one, thus producing an indestructible wick. Th[e] wires which connect the battery with the apparatus are coate[d] with silver, enclosed in india-rubber, and have an outsid[e]

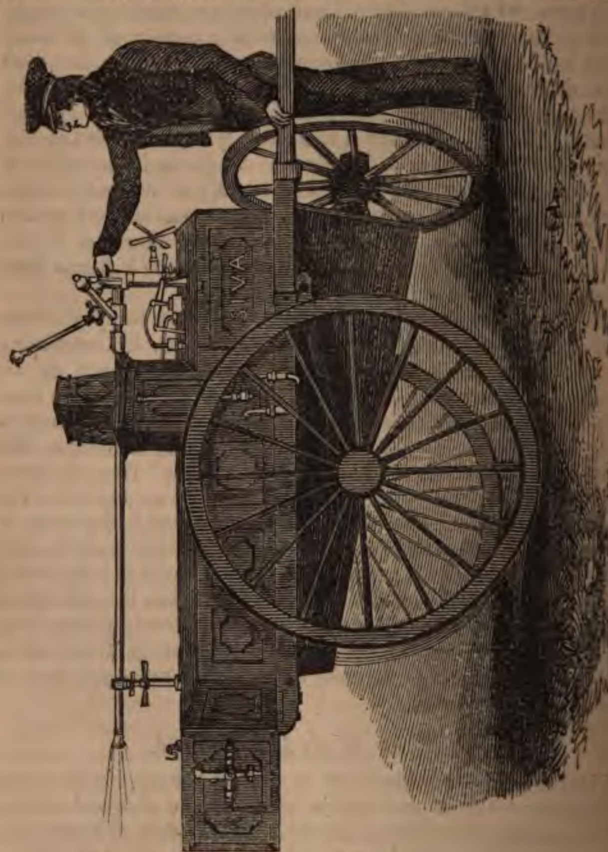


Fig. 343.—The Electro-Galvanic Gun.

coating of braided hemp, the whole being as pliable as pack-thread. Midway between the light and the voltaic battery is a brass standard a few inches high, with which the wires are connected, and by pressing a button on the top of this, simple as the key of a piano, the light can be given in flashes of as long or as short a duration as the operator pleases. This is, however, more correctly carried out by a small instrument of Mr. Way's, which consists of a piece of clockwork, having in front a revolving disc, the face of which is covered with numerous holes with pins to fit in as may be required. In front of the disc are two small cylinders with pistons and arms attached. As the disc revolves, the pins in its face lift the pistons in the cylinders and cut off the connexion between the battery and the lighting apparatus, thus producing flashes of light of any duration that may be required, with their accompanying intervals of darkness, well adapted for a revolving light, or as a code of signals for night service.

A very ingeniously constructed gun, fired off by the agency of a galvanic battery concealed within itself, was at one time exhibited in London, which discharged balls five-eighths of an inch in diameter at the rate of 1000 per minute (fig. 343).

Animal Electricity.

Galvani's experiments convinced him that a particular form of electricity, denominated by him animal electricity, existed in animals; he believed that he merely excited and rendered sensible this electricity by coating a nerve and muscle with metals, but did not regard the latter as the real source.

His celebrated experiment, though so well known, is one really of so remarkable a character, that, repeat it as often as we may, it can never be looked at without some feeling of delight. To perform it, take the legs of a frog, denuded of their skin, and attached by the lumbar nerves to a portion of the spine (fig. 344). Allowing them to rest on a glass plate, place a piece of zinc in contact with the nerves, and allow the feet to rest on a thin slip of silver, in size about the same as the zinc. They will remain at rest, and appear, as they indeed are, dead and powerless, until called into action, by connecting them with a piece of wire, one end of which must touch the zinc, and the other the silver. Instantly the legs will be seen to contract, and kick away the silver plate. It has been stated

by Professor Matteucci, that this curious observation was not original with Galvani, but was made some time before by the celebrated Swammerdam, and the experiment exhibited by him in the presence of the Grand Duke of Tuscany. But,

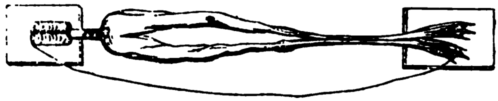


Fig. 344.

however that may be, shortly after the announcement of Galvani's discovery, Professor Volta, of Pavia, in repeating this and other analogous experiments, arrived at a different conclusion as to their explanation, and he showed that the electricity was really excited by the metals, and the contraction of the muscles of the frog was only an index of its existence. Although this and other theories obscured for a time the views and researches of the illustrious Galvani, attention was again drawn to them by the experiments of his nephew, Professor Aldini, of Bologna. He was inspired with so much zeal in the defence of his uncle's theory, that he travelled through France and England for the purpose of demonstrating the truth of his views; and in the presence of the medical officers and pupils of Guy's Hospital, in the year 1803, supported and defended a series of propositions so satisfactory and conclusive, that he was presented by his auditors with a gold medal commemorative of his labours.

Professor Aldini's propositions and conclusions are so important, and of such high interest, that we shall now briefly refer to some of them, as they demonstrate the existence of free electricity in animals, as will appear to all conversant with this branch of physiology.

Prop. 1.—"Muscular contractions are excited by the development of a fluid in the animal machine, which is conducted from the nerves to the muscles without the concurrence or action of metals."

Exp. A.—In proof of this statement, Aldini procured the head of a recently-killed ox. With the one hand he held the denuded legs of a frog, so that the portion of the spine, still connected with its lumbar nerves, touched the tip of the tongue, which had been previously drawn out of the mouth of the ox

(fig. 345). The circuit was completed by grasping with the

Fig. 345.

other hand, well moistened with salt and water, one of the ears. The frog's legs instantly contracted; the contractions ceasing the instant the circuit was broken by removing the hand from the ear. The intensity of these contractions was much increased by combining two or three heads so as to form a sort of battery, just as Matteucci, forty years afterwards, found to be the case with his pigeon and rabbit battery.

Exp. B.—Aldini, having soaked one of his hands in salt and water, held a frog's leg by its toe, and, allowing the ischiatic nerves to be pendulous, brought them in contact with the tip of his tongue. Contractions instantly ensued from a current of electricity traversing the frog's leg in its route from the external or cutaneous to the internal or mucous covering of the body. By this very interesting experiment, Aldini demonstrated the existence of the musculo-cutaneous current. Aldini, in connexion with this experiment, declares that the pendulous nervous filaments were distinctly attracted by the tongue; and to this marvellous and hitherto uncorroborated statement calls to witness Sir Christopher Pegge and

Dr. Bancroft, to whom he states he showed this experiment at Oxford.

Exp. C.—The proper electricity of the frog was found by Aldini to be competent to the production of contractions. For this purpose he prepared the lower extremities of a vigorous frog, and, by bending up the leg, brought the muscles of the thigh in contact with the lumbar nerves (fig. 346): contractions immediately ensued. This experiment is now a familiar one, and has been repeated and modified lately by Müller and others.

Fig. 346.

Exp. D.—A ligature was loosely placed round the middle of the crural nerves, and one of the nerves applied to a corresponding muscle; contractions ensued; but, on tightening the ligature, convulsions ceased.

This statement is very important, as upon its accuracy or error depends what has been regarded one of the tests of the identity or diversity of the electric and nervous agencies. It was repeated, soon after Aldini's announcement of the fact, by an Italian physician of celebrity, Signor Valli, who commenced his researches indeed in 1792, only a year after the publication of Galvani's discovery; and he found if the ligature was applied *near the muscle it did not allow the contraction to occur, but if nearer the spine it did not prevent it.* It has been since found by Prof. Matteucci, that if care be taken to insulate the nerve, a ligature *does* arrest the contraction, as well as the passage of a very weak artificial electric current.

"Little occurred," writes Dr. Bird, "during the subsequent thirty-five years to modify these conclusions, or add to their interest, repeated and extended by numerous observers, especially by Humboldt, and more lately by Müller. They were almost lost in the blaze of novelty surrounding the vast discoveries made on the constitution of inorganic matter by the magic pile of Volta, an instrument which, in the hands of our late talented countryman Sir Humphry Davy, resolved many bodies previously considered simple into their constituent elements, and quite changed the face of chemistry; and still

more recently, directed by the gifted genius and vast attainments of a Faraday, has led to the discovery of new sciences, and of properties of matter before undreamed of; indeed, has promised to lay open to us the secrets of the working of the invisible agents presiding over the ultimate constitution of material masses."

It may now be asked, what proof do we possess that the action on the muscular fibre of a frog's leg is really produced by electric currents? It is true that this is generally taken for granted, but still it is important to review our proofs. One great evidence in favour of this opinion is at once found in the fact, that contractions produced in frogs can only be excited when connexion is made between a nerve and muscle by a conductor of electricity, all other bodies interfering with the production of this phenomenon. The only thing approaching to a more positive proof before the researches of Matteucci, is an experiment of Valli, in which he formed a sort of battery of fourteen prepared frogs, and, by the electricity thus accumulated, succeeded in producing the phenomena of divergence in a delicate electrometer. It is to be regretted that no accurate account of this experiment has been left on record; for, if true, it must be regarded as most satisfactory in proving the identity of the electricity of the frog, with that obtained from other sources.

The recent researches of Prof. Matteucci, of Pisa, have, however, completely set this matter at rest. He has incontestably proved that currents of electricity are always circulating in the animal frame, and not limited merely to cold-blooded reptiles, but are common to fishes, birds, and mammalia.

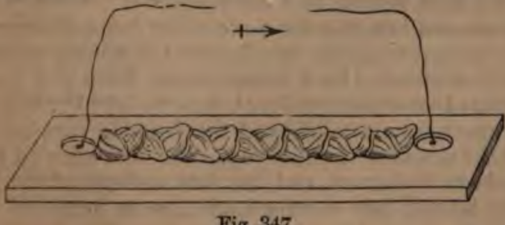


Fig. 347.

From the researches of this philosopher, it appears that a current of positive electricity is always circulating from the

interior to the exterior of a muscle; and that, although the quantity developed is exceedingly small, yet that, by arranging a series of muscles having their exterior and interior surfaces alternately connected, he developed sufficient electricity to produce energetic effects (fig. 347).

By thus arranging a series of half thighs of frogs, he succeeded in decomposing iodide of potassium, in deflecting the needles of a galvanometer to 90°, and, by aid of a condenser, caused the gold leaves of an electrometer to diverge. When more delicate tests of the electric currents were made use of, their existence was demonstrated in the muscles of all animals, and even of man himself.

Professor Matteucci availed himself of this circumstance in his contrivance of the frog-galvanoscope. This is made by skinning the hind leg of a frog, and separating it from the trunk, taking care to leave as long a piece of *sciatic nerve* projecting as possible. The leg must then be placed in a glass tube, the nerve hanging over (fig. 348). In using this contrivance, all that is necessary is to let the piece of nerve touch simultaneously in two places the part where electric condition is to be examined. If a current exists, the muscles of the leg will become convulsed at the moment of contact.

Fig. 348.

In this way the Professor detected a current in man; by making a clean incision into the muscles of a recently amputated limb, and bringing the nerve of the frog-galvanoscope in contact at once with the two lips of the wound, contraction instantly occurred. In a recent paper, Matteucci has fully corroborated the statement, long before made by Dr. Wilkinson, of the marvellous sensibility of the irritable muscles of the frog to the stimulus of electricity. For even after an electric jar has been discharged, and the two surfaces of the jar repeatedly brought into communication, so as to get rid of any residual charge, and lose all influence on the more delicate electrometer, its electric equilibrium is still sufficiently disturbed to excite convulsions readily in the frog-galvanoscope.

In pigeons and fowls, as well as in eels and frogs, currents were readily demonstrable; indeed, by alternating a series of the former by approximating their sides, the raw surface of the muscles of which had been exposed by a quickly made cut, Matteucci formed a sort of battery resembling that made of the thighs of frogs. The result of this experiment has proved that energetic currents existed in hot- as well as cold-blooded animals; indeed, more intensely, but very soon disappearing on the death of the animal. These researches completely corroborate the statements and experiments of Aldini made many years earlier, especially that very remarkable one before alluded to, in which he produced contractions of the legs of a frog by bringing them in contact with the tongue of an ox. By means of the frog-galvanoscope, not only the existence, but the direction of a current can be discovered; for if the leg be kept for a short time before using it, so as to diminish a little its sensibility, the muscles will contract on *making* contact with the body under examination, if the positive electricity *passes* from the nerve to the leg, whilst it will contract on *breaking* contact if the electricity is moving in the opposite direction. Using this delicate test for an electric current, Matteucci discovered that the intensity of such currents rises in proportion to the rank occupied by the animal in the scale of being, their duration after death being in the inverse ratio. He likewise discovered, that when a mass of muscle belonging to a living animal, or one recently dead, was placed in contact with a piece of wire, so that one end of it touched the tendon, and the other the body of the muscle, a current could always be detected circulating in the mass in the direction from the tendon to the external surface of the structure. He further demonstrated the very important fact, that every thing which decreases the *vis vitæ* of the animal, diminishes the evidence of electricity immediately after death. Thus, when frogs were killed by asphyxia, either by immersion in sulphuretted hydrogen, or water freed from air, the electricity detected in their femoral muscles sank to a minimum; whilst the thighs of frogs whose hearts had been previously removed, gave less evidence of the existence of this important agent than those which had not been so injured. It is well known that certain fishes, the torpedo, &c., possess a peculiar apparatus by which they are enabled to accumulate the electricity developed

by the vital processes going on in their structures, and thus produce the ordinarily recognized effects of tension. This endowment is, however, peculiar to very few creatures, and the electricity developed in the frames of other organisms is only to be detected by comparatively delicate tests. It is, however, very remarkable, that in the *Batrachians* generally, especially the frog, an electric current, denominated by Matteucci the "proper current," possessing some approach to tension, and capable of deflecting the needle of a galvanometer to 5°, can readily be detected; its direction is always definite from the feet towards the head. This curious and remarkable fact was first pointed out by Nobili, and afterwards accurately studied by the Pisan philosopher, to whose researches we have so often referred.

Space will not allow us to do justice to the numerous *savans* who have been engaged in the investigation of animal electricity. We may, however, refer to a work recently published on this subject by Mr. Smee, and extract from his book one of the earliest of his experiments. Having obtained the ar-

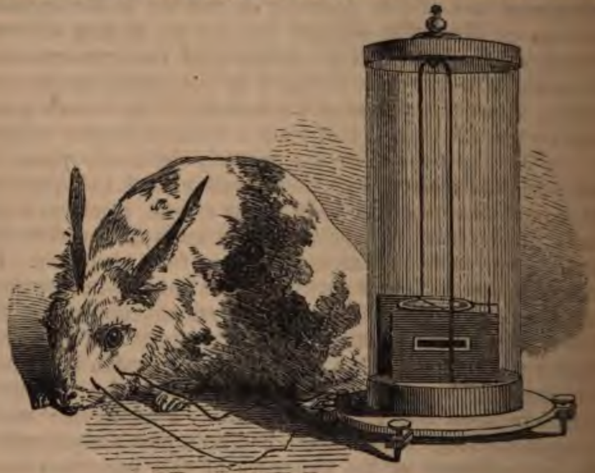


Fig. 349.

rangements necessary for measuring feeble currents of electricity, he applied his test to the living animal in the following

manner:—The animal (represented in fig. 349) was a rabbit, into the cheek muscle of which he introduced a sewing-needle, whilst a second needle was placed in the cellular tissue beneath the skin. After leaving them for a few minutes, so that they might be in the same state, they were connected with the galvanometer, without sensible deflection of the needle. In a few moments more, the animal, not liking its treatment, made an attempt to bite; the mechanism of volition was instantly exhibited by the deflection of the galvanometer. A piece of wood was then given to the animal to bite, upon which it used all its powers of mastication; and, by catching the oscillation of the needle, a very powerful electric current was exhibited. In this experiment the deflection of the needle proved the existence of a voltaic current during the action of biting, and thus denoted the mechanism of the force employed to throw the muscles into operation.

Our illustration (fig. 350) represents the arrangement of an experiment recently performed by M. Dubois-Reymond, a gentleman eminent in the study of "organic electricity." A cylinder of wood is fixed firmly against the edge of a table; two vessels filled with salt and water are placed on the table, in such a position that a person grasping the cylinder may at the same time insert the fore-finger of each hand into the water. Each vessel contains a metallic plate, and communicates by two wires with an extremely sensitive galvanometer G. In the instrument employed by M. Dubois-Reymond, the wire made 24,000 turns. The apparatus being thus arranged, the experimenter grasps the cylinder of wood firmly with both hands, at the same time dipping the fore-finger of each hand in the saline water. The needle of the galvanometer remains undisturbed; the electric currents passing by the nerves of each arm, and being of the same force, neutralize each other. Now if the experimenter grasp with energy the cylinder of wood with the right hand, the left hand remaining flaccid and free, immediately the needle will move from the west to the south, and describe an angle of 30°, 40°, and even 50°; on relaxing the grasp, the needle will return to its original position. The experiment may be reversed by employing the left arm, and leaving the right arm free; the needle will in this case be deflected from the west to the north. This reversing the action of the needle, by the contraction of the muscles of the

right and left arm alternately, places beyond all doubt the question of the electric current being induced through the agency of the nervous system.

Fig. 390.

Three conditions are necessary for the success of this experiment;—1. great muscular force; 2. the precaution to contract the muscles of only one arm at the same time; 3. that

the skin of the hand should be soft, quite clean, and free from any kind of wound, however small.

If the experimenter is too feeble, the needle is scarcely disturbed. If both arms are contracted unequally at the same time, the deflection only shows the excess of force of one arm as compared with the other. When the skin of the hand is thick and hardened, it is a bad conductor of electricity, and the least scratch or wound gives rise to chemical actions which develope of themselves the electric currents. The result of this experiment is, that the human will, producing a muscular contraction, causes a deflection of the needle.

The theory thought to accord best with the experiments made is the following:—The nerves are the channels or seats of continuous currents of electricity, which contraction of the muscles, pain, and other circumstances may interrupt. At the moment the fingers are plunged into the saline water, the needle remains perfectly quiet; the currents passing through both arms and in opposite directions neutralize each other. When one arm only is contracted, the electric current is interrupted in this arm; the current from the other arm, acting alone, causes the needle to deflect according to the muscular or electric force developed. The nervous phenomena have, then, a close analogy with those of electricity. But we have at present no proof of the *identity* of the latter with nervous force.

Dr. Wilson Philip proved that when he severed the eighth pair of nerves in rabbits, the food in their stomachs remained undigested, and they died of suffocation; but after dividing the nerves, and distributing the galvanic power below the severed nerve to a disc of silver opposite the stomach, the operation of breathing and digestion proceeded as usual. The doctor also found he could continue the motion of the heart and circulation after the brain and spinal marrow of a rabbit were removed; and concludes his investigations by saying, "hence galvanism seems capable of performing all the functions of the nervous influence in the animal economy; but, obviously, it cannot excite the functions of animal life, unless when acting on parts endowed with the living principle."

Electricity appears to be bestowed upon certain animals both as a mode of defence and of destruction. The most remarkable creature known is the Raia torpedo, a flat-fish, seldom twenty

inches long, found on the coasts of Europe, fig. 351. The elec-

Fig. 351.

trical apparatus is placed on each side of the gills, where it extends from the upper to the lower surface, covered by the skin of the body. When one hand is placed on the upper and the other on the lower surface, a smart shock is felt; the organs of electricity answering to the positive and negative sides of a Leyden jar. This natural electricity can be withdrawn from the animal by means of a conductor, and a shock is felt through a circuit formed by several persons joining hands. No spark can be obtained, nor can electric attraction and repulsion be produced; but strong solutions of common salt, nitrate of silver, and superacetate of lead have been decomposed by its electrical powers, and steel magnetized. When the torpedo sends forth a shock, it depresses its eyes, contortions of the body follow, and it appears to have a control over the power.

In the accompanying figure (fig. 351) *a* represents the dorsal fin; *b* part of the skin turned over, showing the right electric organ, consisting of white pliant columns resembling a small honeycomb; *c* the nostrils, in a crescent form; *d* the mouth, which has several rows of small teeth; *e e* the ten breathing apertures; *f f* outer margin of the greater lateral fin; *g g* two smaller fins; *h* the tail fin.

The gymnotus, or electrical eel (fig. 352) is an inhabitant of

the freshwater lakes and rivers of the warmer regions of America and Africa. Its body is smooth and without scales, a long ventral fin extends from behind the head to the extremity of the tail; the mouth is armed with sharp teeth, and projecting into it are numerous fringes, which from their nature appear to serve a purpose in respiration; the gullet is short, terminating in a capacious stomach; the whole cavity of the abdomen is not more than seven inches long; besides the alimentary canal, the heart, liver, and upper part of the air-bladder. The rest of the animal is made up of the electrical organs and muscles of progression, together with an air-sac, which runs beneath the spine the whole length of its body. They are about six feet in length.

The skin being turned over, the two electrical organs are seen on each side. They are of two parts, flat partitions or septa, and cross divisions between them. The outer edges of these septa appear in parallel lines nearly in the direction of the longitudinal axis of the body; they ar thin membranes nearly parallel to one another, their breadth nearly the semidiameter of the body, but of different lengths, some being as long as the whole organ.

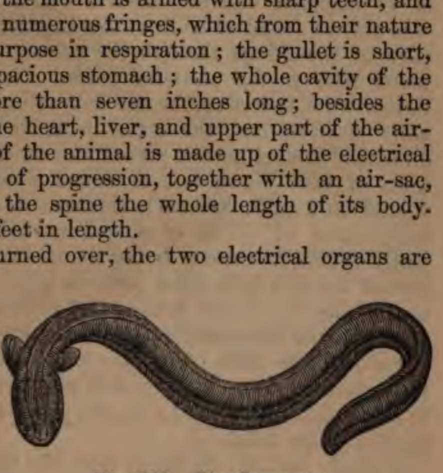


Fig. 352.—The Gymnotus.

In the accompanying figure (353) *a* represents the head; *b* the cavity of the belly; *c* the back when the skin is not removed; *d d* the ventral fin; *e e* the skin turned back; *f f* the lateral muscles of the fin; *g g g* the large electrical organ; *h h* the small organ.

When small fishes are put into the water in which the gymnotus is kept, it will first stun, or perhaps kill them as if by a stroke of lightning, and if hungry it will then devour them. If the stunned fish be removed to another vessel of water, it will speedily recover.

The gymnotus seems to know whether substances are conductors, as it will only exert its electrical powers on those that are so.

A powerful shock is obtained when one hand is placed near

the head and the other near the tail. Faraday fitted a kind of saddle upon one for the purpose of experiments, and found that a galvanometer, not very delicate, was affected to the extent of 40 degrees; and the electric current was always found to be from the interior parts of the animal through the galvanometer wire to the posterior parts. The former were, therefore, for the time externally positive, and the latter negative; an annealed steel needle, placed in a little helix of twenty-two feet of silked wire wound on a quill, became a magnet; decomposition of iodide of potassium was easily obtained. On comparing the middle part of the fish with other portions before and behind it, it was found that within certain limits the condition of the fish externally at the time of the shock appears to be such, that any given part is negative to other parts anterior to it, and positive to such as are behind it.

Fig. 353.

A single medium discharge from the animal is calculated to be equal to the electricity of a Leyden battery of fifteen jars, containing 3500 square inches of glass coated on both sides and charged to its highest degree; and of this force it can give double and triple shocks following instantaneously.

Mr. Gassiot fused gold leaves with the electricity from one of these eels.

When a number of persons dip their hands into the vessel in which one of the animals is kept, they all receive a shock differing in intensity according as they are situated with regard to the direction of the current.

We must not omit the mention of some remarkable experiments by the late Mr. Crosse, whom Dr. Buckland introduced to the British Association, at Bristol, in 1836, as "a philosopher who had made great discoveries by the use of a brick with a hole in it immersed in a pail of water." This gentleman, by keeping up the action of a battery for months on different substances, produced an extraordinary variety of minerals. In a large, common, glazed salting-pan, filled with the spring-water of the country, a common red brick was laid horizon-

tally, each end resting on a half-brick of the same sort. The two ends of the brick were connected respectively with the positive and negative terminations of a sulphate of copper battery of nine pairs of nine-inch plates; the upper surface of the brick was covered with clear river-sand. At the termination of a quarter of a year the apparatus was taken apart, and the following observations were made:—On attempting to lift the whole brick from the two half-bricks that supported it, it was found, that while the positive end was easily removed from the brick below it, the negative end required some little force to separate it from its support; and when the two were wrenched asunder, it was observed that they had been partially cemented together by a tolerably large surface of beautiful snow-white crystals of arragonite, thickly studding that part of the brick in groups, the crystals of each radiating from their respective centres. Here and there were formed, in some of the little recesses in the brick, elevated groups of needle arragonite, meeting together in a pyramidal form in the centre; while in the open spaces between were some exquisitely-formed crystals of carbonate of lime, in cubes, rhomboids, and more particularly in short six-sided prisms with flat terminations, translucent and opake, sufficiently large to determine their form without the use of a lens. The positive end of the brick, and that which supported it, were also covered with crystals, much smaller, and apparently of a different nature. On emptying the water from the pan, there was found at its negative end, at the bottom, a very large quantity of snow-white carbonate of lime to the extent of some ounces in weight, in the form of a gritty powder in minute crystals. Three-fourths of the whole interior of the pan were covered with myriads of crystals of carbonate of lime, so firmly adhering to the pan as not to be separated without the aid of an acid.

It would seem strange, when mentioning Mr. Crosse and his experiments on crystallization, to pass over in silence a circumstance that has excited much discussion. Mr. Crosse was endeavouring to form crystals of silica, when he observed the gradual growth of some insects from the middle of the electrified stone, which on the twenty-sixth day became perfect; and in a few weeks there were hundreds. Fig. 354 shows a magnified view of one of these. The discoverer writes: "I have never given an opinion as to the cause of their birth, and

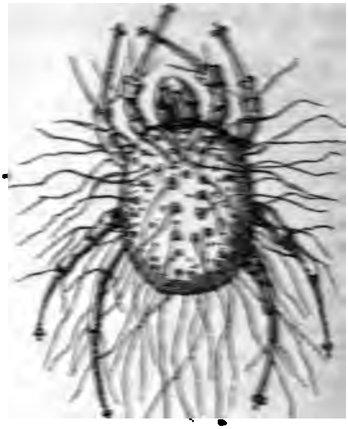


Fig. 334.

for a very good reason—I was unable to form one. The most simple solution of the problem which occurred to me was, that they arose from ova deposited by insects floating in the atmosphere, and that they might possibly be hatched by the electric action. I next imagined, as others have done, that they might have originated from the water, and consequently made a close examination of several hundred vessels filled with the same water as that which held in solution the silicate of potassa. In none of these vessels could I perceive the trace of an insect of that description. I likewise closely examined the crevices and most dusty parts of the room with no better success."

This same hitherto unobserved acarus has been produced in electrified solutions of nitrate and sulphate of copper, of sulphate of iron, sulphate of zinc, fluosilicic acid, and in ferrocyanuret of potassium. Mr. Weeks, the indefatigable experimenter at Sandwich, took every means to free the apparatus of all foreign matter, and to exclude the air, and after the action of a year the same insects were produced. Nevertheless, it cannot admit of a doubt that these insects or their ova, must have been conveyed there by the wind or some other agent, as it is impossible to believe that voltaism or electricity can *create a new being*.

CHAPTER XI.

MAGNETISM.

Man has detected another mysterious power in nature, similar to that of electricity and galvanism, which he has en-

listed in his service, and rendered subservient to his purposes.

Magnetism resembles electricity, and may perhaps be defined as electric polarity of a peculiar kind.

A mineral or ferruginous stone, found commonly in iron mines, of various forms, sizes, and colours, was found to be endowed with the property of attracting iron, of pointing itself in a certain direction, and of communicating the same powers to iron and steel bars; it was called the *loadstone*, *leading-stone*, or magnet.

Plato and Aristotle state that the ancients were acquainted with the attractive and repulsive powers of the magnet; but no mention is made of its directive property, which is of all others the most useful and interesting. But we have it on record that, many centuries before the Christian era, the Chinese, when in a battle, being overtaken by a dense fog, directed the movements of their troops by means of a magnet; to them, then, its *directive properties* must have been familiar. Still its use and application to the purposes of navigation is of comparatively modern date in other parts of this world. It is mentioned by old continental writers in MSS. of the twelfth century; and Cardinal Vetri in his History of Jerusalem, about the date of 1200, names the magnetic needle, and its importance to sea-faring persons. Dr. Gilbert says the compass was brought from China to Italy in 1260, by Paulus Venetus.

From what may be gleaned on the subject from mediæval records, it would seem that the direction of the needle was pretty generally known about the commencement of the fourteenth century. But that this direction was subject to change was as yet a fact unknown when Columbus first ventured to seek the shores of a new world, will appear from the following extract from Washington Irving's 'Life and Voyages of Columbus:' "On the 13th of September, 1492, he perceived about night-fall that the needle, instead of pointing to the north star, varied but half a point, or between five and six degrees to the north-west, and still more on the following morning. Struck with this circumstance, he observed it attentively for three days, and found that the variation increased as he advanced. He at first made no mention of this phenomenon, knowing how ready his people were to take alarm; but it

soon attracted the attention of the pilots, and filled them with consternation. It seemed as if the laws of nature were changing as they advanced, and that they were entering into another world, subject to unknown influences. They apprehended that the compass was about to lose its mysterious virtues; and without this guide, what was to become of them in a vast and trackless ocean? Columbus tasked his science and ingenuity for reasons with which to allay their terrors. He told them that the direction of the needle was not to the polar star, which, like the other heavenly bodies, had its changes and revolutions, and every day described a circle round the pole, but to some fixed and invisible point; and therefore the variation was not caused by any failing in the compass. The high opinion that the pilots entertained of Columbus as a profound astronomer, gave weight to his theory, and their alarm subsided."

That iron became under certain circumstances endowed with the power of the magnet was first observed in 1590 by a surgeon of Rimini; and in 1600, Dr. Gilbert of Colchester wrote a work on magnetic bodies, and termed the extremities of the needle *poles*. Dr. Halley, in 1683, wrote on the theory of the science, and suggested the existence and situation of magnetic poles, of which he believed there were four, and likewise offered suppositions for the change in the direction. Mr. Graham, a London mathematical instrument-maker, in 1722 noted most carefully the daily variation, and found that seasons as well as hours made a difference. Although the making of artificial magnets was long known, still they were weak in power until the discovery of a better mode was contrived by Dr. Knight, about 100 years ago, and other philosophers afterwards improved upon his method. To A. C. de Coulomb we owe the discovery that magnetic power, like electricity, resides on the surfaces of iron bodies, and does not penetrate into the interior of solid bodies. Coulomb added much to our knowledge on the manufacture of artificial magnets, and in 1802 announced that all bodies are subject to magnetic influence, which he suspected to be caused by portions of iron diffused in them. But since his time other metals besides iron have been proved to be magnetic. Indeed Faraday has discovered that all metals are magnetic, but that each requires a certain temperature for development.

Professor Barlow, of the Royal Military Academy at Woolwich, after investigating the effect of the iron in a man-of-war on the compass, the proper action of which it greatly disturbed, found that a plate of about five pounds weight, placed in a certain position near the needle, would represent and counteract the attraction of all the other iron in the ship. This was tested in all parts of the world, and found to be a fact of so much value that the Government Board gave for the invention the highest reward in its power. Captain Parry, on this subject, says, "Such an invention as this, so sound in principle, so easy in application, and so universally beneficial in practice, needs no testimony of mine to establish its merits; but when I consider the many anxious days and sleepless nights which the uselessness of the compass in these seas had formerly occasioned me, I really should have esteemed it a kind of ingratitude to Mr. Barlow, as well as great injustice to so memorable a discovery, not to have stated my opinion of its merits, under circumstances so well calculated to put them to a satisfactory trial."

Dr. Dalton, Professor Hanstein, M. Arago, Captain Back, and others have made many observations on the great derangement of the needle which arises on the appearance of the aurora borealis, which is always in the direction of the magnetic pole. Although the Northern Lights are rarely seen further south than Scotland, yet they disturb the magnetic needle at Paris.

The loadstone, as found in its native state, consists of two oxides of iron, with a small quantity of quartz and alumina. It is principally obtained from Arabia, China, Siam, Norway, and Sweden; and sometimes a little has been found among the iron ore of England. Small loadstones are more energetic than large ones. Sir Isaac Newton had one in his ring that lifted two hundred and fifty times its own weight.

Properties of the Magnet.

There are certain properties which are characteristic of the magnet, and when other bodies exhibit them, they are for this reason called *magnetic*.

The first property is *polarity*. If a bar of loadstone, or a bar or needle of steel that has been rendered magnetic, be

poised at its centre so that it will swing freely, it will be found that one end points to the north, and the opposite end to the south. The ends thus pointing are called the poles of the magnet. The needle does not in all parts of the world point directly to the north star. It is attracted to a part of the earth called the magnetic pole, in the arctic regions. The difference between its indication and the true north pole is termed the *deviation* of the magnet. In some parts of the world it is very considerable. Into how many soever parts we cut the magnet, one end of each will still point to the north, the other to the south. The magnetic force at each end is different in nature. It is supposed that each atom has, as it were, boreal or north magnetism on one side, austral or south magnetism on the other. But as in the case of a metal bar suffering electrical induction, the opposite forces are chiefly collected towards the extremities or poles. If a magnet be bent into a horse-shoe shape, as is frequently done in cases where it is not required as a compass, the two ends are still possessed of polarity, and exhibit the two opposite kinds of magnetism. In the property of polarity (not pointing to the north, but accumulation of opposite forces at opposite ends) we at once trace a resemblance between magnetism and induced electricity. We shall soon see further that under certain circumstances electricity may be made to produce magnetism, or magnetism to generate electricity. They are probably varieties of one and the same force.

The second property of the magnet is the power of attracting iron. Either pole will attract or even lift pieces of iron. Iron filings will cluster round and cling to both poles. Towards the centre of the magnet little or no attraction exists.

Attraction and repulsion of another magnet is a third property. Two poised magnets being brought near each other, the north pole of one is found to repel the north pole, but to attract the south pole of the other: just as similar kinds of electricity are mutually repulsive, and opposite kinds attractive.

A fourth property is the power of causing magnetism by induction in a piece of soft iron. A piece of soft iron, in contact with one or both poles of a magnet, becomes itself a magnet while in contact. The part next the pole of the inducing magnet possesses magnetism of an opposite nature, the

part furthest from it has magnetism of the same kind as the pole itself. This is just what occurs in ordinary electric induction (see page 446). A piece of soft iron, placed transversely across the two poles of a horse-shoe magnet, is called the *armature*. This armature intensifies and augments the magnetic power of the poles.

A fifth magnetic property is *the power of rendering other bodies magnetic*, especially steel. The soft iron bar is a magnet only while it hangs to the poles of the permanent magnet; but if a magnet be drawn in one direction, several times, along a steel bar, that bar becomes in every respect a permanent magnet itself. If the original magnet be now drawn along the bar in the opposite direction, its polarity is destroyed, and it ceases to be magnetic. In this simple manner steel needles may be formed into perfect magnets by means of the loadstone.

The earth itself acts on the needle simply as a great magnet. It is thought to have two fixed magnetic poles, one to the north, another to the south; also two other poles, towards the north and south, but moveable, or liable to fluctuation. In our latitude the needle points *downwards*, as well as northwards, towards the north magnetic pole of the earth. The degree of this downward inclination is called the *dip* of the needle.

The *axis of a magnet* is a right line which passes from one pole to another. The *equator of a magnet* is a line perpendicular to the axis, and exactly between the poles. The *magnetic meridian* is a vertical circle in the heavens, which intersects the horizon in the points to which the magnetic needle directs itself when at rest. The direction of the magnetic needle is not the same in all parts of the world, nor in the same place at different times.

These poles, in different parts of the earth, are also differently inclined towards a point under the horizon; and though contrary to each other, help mutually towards the magnet's attraction and suspension of iron.

Heat to a certain degree destroys magnetic power. The earth, being a magnet, is capable of causing magnetism in iron under certain conditions. If a magnet be heated red-hot, and again cooled, either with its south pole towards the north, in a horizontal position, or with its south pole downwards, in

[illegible]

[illegible] differs from [illegible] in the fact that [illegible] in the same body, and that one [illegible] while it may be remembered that one kind of [illegible] can be excited from one body and another from a different one. The [illegible] polarity of the magnet is the property that renders it so serviceable to the purposes of navigation, mining, and travelling in unknown countries.

Newton, in his 'Principia,' speaks thus of magnetic force contrasted with that of gravity. He says, "The magnetic attraction is not as the matter attracted; some bodies are attracted

more by the magnet, others less; most bodies not at all. The power of magnetism in one and the same body may be increased and diminished, and is sometimes far stronger for the quantity of matter than the power of gravity, and in receding from the magnet decreases not in the duplicate, but almost in the triplicate proportion of the distance."

The Compass.

To construct the *Mariner's Compass* it is only necessary to take a magnetized needle, nicely balance and place it in a round box covered with glass, having a card or paper on which are

Fig. 355.

marked 32 points; that is to say, the circle or horizon divided into 32 parts. Every point is a 32nd part of 360°, which is equal to $11\frac{1}{4}°$; a half point is equal to $5° \; 37' \; 30''$; and a quarter point equal to $2° \; 48' \; 45''$. North, East, South, and West are termed the four *cardinal points*.

On the edge of the box two pieces of brass, *b b* (fig. 356), are fixed upright in a circular ring *a a*, having oblong aper-

tures cut in the centre termed sight-holes; a fine wire or hair is stretched down the centre of one of the upright pieces, the other having a fine slit only in it, then by applying the eye to one aperture until the wire or hair of the other passes over the object and the centre of the card, the angular distance or azimuth from the magnetic meridian is ascertained. This arrangement forms the *azimuth compass*.

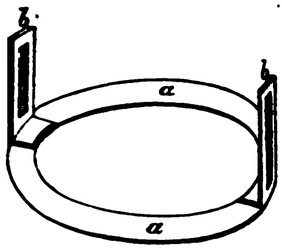


Fig. 356.

The place where the needle remains at rest is called the *magnetic meridian*. At Greenwich the magnetic meridian makes with the astronomical an angle of $23\frac{1}{2}°$ west. This variation from the direct north has been observed to be 23° 4′ 48″, to 23° 24′ 19″. It increases westward from 7 A.M. till about 1 P.M., about $7\frac{1}{4}'$ of arc; it then returns eastward till about 11 P.M., about $8\frac{1}{4}'$ of arc. This is called the *variation of the compass*, or *magnetic declination* west or east. The diurnal range in the summer of 1846 was 15′ 14″; in winter 11′ 53″; and for the year 13′ 34″; it was smallest in January and largest in September. Going from London and proceeding west on the Atlantic Ocean, the magnet is found to attain its greatest tendency towards the west; proceeding onwards it returns towards the north, and at the east of the United States of America it becomes due north, and further westward it becomes east. Going from London to the east, the western declination lessens, and at the eastern part of Russia it is due north; proceeding further east the variation becomes gradually more easterly.

If a piece of iron be balanced and afterwards magnetized, and placed on its former balancing point, it will be found to have lost its previous equilibrium, and the north point will incline towards the earth about 70°. This is called the *dip* of the needle. Conveying this needle towards the north, the dip increases until it becomes vertical. About the equator there is no dip. Towards the south pole it dips to the south until it becomes vertical. The mean magnetic dip for 1846 at 21 hours at Greenwich was 68° 58′·6″, and at 3 hours 68° 57′·6″.

The Magnetic Poles.

As the magnetic poles which attract the magnet do not correspond with the poles of the earth, it is plain that the needle cannot point due north and south except in those countries where the magnetic and true meridian coincide, and it is this that causes the variation of the needle. The south magnetic pole is believed to be somewhere about latitude 65° south, and longitude 130° west of London.

Of the discovery of the North Magnetic Pole, Commander Ross writes, "We reached the calculated place at eight in the morning of the 1st of June, 1831. I believe I must leave it to others to imagine the elation of mind with which we found ourselves now at length arrived at this great object of our ambition; it almost seemed as if we had accomplished every thing that we had come so far to see and to do; as if our voyage and all its labours were at an end, and that nothing now remained for us but to return and be happy for the rest of our days. . . . . .

"The land at this place is very low near the coast, but it rises into ridges of fifty or sixty feet high about a mile inland. We could have wished that a place so important had possessed more of mark or note. It was scarcely censurable to regret that there was not a mountain to indicate a spot to which so much of interest must ever be attached; and I could even have pardoned any one amongst us who had been so romantic or absurd as to expect that the magnetic pole was an object as conspicuous and mysterious as the fabled mountain of Sinbad, that it was even a mountain of iron, or a magnet as large as Mont Blanc. But Nature had here erected no monument to denote the spot which she had chosen as the centre of one of her great and dark powers. . . . .

"The necessary observations were immediately commenced. . . . . The place of the observatory was as near to the magnetic pole as the limited means which I possessed enabled me to determine. The amount of the dip, as indicated by my dipping-needle, was 89° 59′, being thus within one minute of the vertical; while the proximity at least of this pole, if not its actual existence where we stood, was further confirmed by the action, or rather by the total inaction, of the several horizontal needles then in my possession. These were suspended

in the most delicate manner possible, but there was not one which showed the slightest effort to move from the position in which it was placed; a fact which even the most moderately informed readers must now know to be one which proves that the centre of attraction lies at a very small horizontal distance, if at any.

"As soon as I had satisfied my own mind on this subject, I made known to the party this gratifying result of all our joint labours; and it was then, that amidst mutual congratulations, we fixed the British flag on the spot, and took possession of the North Magnetic Pole and its adjoining territory in the name of Great Britain and King William IV. We had abundance of materials for building, in the fragments of limestone that covered the beach; and we therefore erected a cairn of some magnitude, under which we buried a canister, containing a record of the interesting fact; only regretting that we had not the means of constructing a pyramid of more importance, and of strength sufficient to withstand the assaults of time and of the Esquimaux. Had it been a pyramid as large as that of the Cheops, I am not quite sure that it would have done more than satisfy our ambition, under the feelings of that exciting day. The latitude of this spot is 70° 5′ 17″, and its longitude 96° 44′ 45″ west."

Some time before this actual observation, Professor Barlow had distinctly marked the situation of the North Pole as calculated by him from the variations of the needle in different parts of the world.

The variation of the needle is further subject to a gradual change through time; when first known, the variation as observed by Norman was 11° 15′ eastward; from 1657 to 1662, it pointed due north in London; it then began gradually going to the westward, and in 1815, according to Colonel Beaufoy, it reached its maximum, being 24° 27′ 18″ westerly, since which period it has been gradually decreasing. Thus it would appear that the magnetic poles are not stationary, but revolve round some central point in so many centuries. It is to explain this that two moveable poles have been supposed to exist. The greatest variations were observed by De Langle between Greenland and Labrador, which was 45° west, and by Capt. Cook in 60° south latitude, and 92° 35′ longitude, when it was 43° 6′ east of the geographical meridian.

Magnetic Observations.

The magnetic variations, and more especially those influencing the meteorologic changes on the earth's surface, receive a large amount of attention from scientific men in all parts of the globe. The Government have caused to be erected the Royal Observatory at Greenwich for magnetic and meteorological observation. It is now under the direction of Mr. Glaisher, who has, at a vast amount of personal labour, reduced his practice to a system, and succeeded in establishing, in various parts of the country, numerous other stations for meteorological observations; all are in daily communication, and the results are considered so important that they form a part of the quarterly reports of the Registrar-General. It may not prove uninteresting to those of our readers who are able to enter into details of a somewhat recondite character, to be furnished with a history of the more important instruments in daily use at the Greenwich Observatory.

In the year 1836, the Astronomer Royal, Mr. Airy, submitted to the Board of Visitors of the Royal Observatory, a plan for the erection of a Magnetical Observatory. In consequence of the interest taken in the proposal by the Board of Visitors, the building was erected in the spring of 1838, and it was put to a practical use in 1839, on days pre-arranged for simultaneous observations. In the summer of 1839, Mr. Airy recommended to Government the prosecution of a series of magnetical and meteorological observations here, in correspondence with the observations of Captain Ross in the antarctic expedition, and with the observatories erected under the authority of the Board of Ordnance and the East India Company in several foreign stations. On the Government assenting, immediate measures were taken for carrying out the plan.

From November 9, 1840, begins the series of observations which is properly characteristic of the Observatory. Regular observations have since been taken, without intermission, except on Sundays. The regular work of the establishment is as follows. At every even hour of Göttingen mean time (night and day), to observe the position of each of the three magnets, with the readings of the thermometers enclosed in their boxes; the height of the barometer, and the wet and dry thermometers; to inspect the electrical instruments; to record

the direction and estimated strength of the wind; to estimate the proportion of the sky which is covered by cloud, and to note the kind of cloud; to observe whether there be different currents in the atmosphere, or any other meteorological phenomena worthy of note; to observe the dew-point four times a day; to observe the inclination of the magnet to the horizon (technically called the dip) four times in the week; to take incessant observations of the magnets when aurora, or any other unusual circumstance, seems to make it desirable; to observe continually whether the electrical instruments are affected; to observe the three magnets at intervals of 2½ minutes during twenty-four hours on one term-day in each month; to adjust the papers, &c. for the self-registering anemometers; to ascertain the quantity of rain collected at four different heights above the ground each day; to make occasional observations on the measures of halos, coronæ, and glories, the degree of solar and terrestrial radiation, the intensity of the sun's rays, &c.

Each of the instruments in use requires to be separately described.

The annexed cut (fig. 357) represents the *declination-magnet*: *a*, a perspective view of the magnet; *b*, a brass frame, carrying a lens; *c*, a brass frame carrying two plain glasses, between which is a cross of delicate cobwebs; *d*, the lower part of the suspension apparatus, with the torsion-circle attached; *e*, the suspending skein of silk fibre, which rises 8 feet 9 inches, then passes over a pulley at *f*, and then over another at *g*, and is then attached to a piece of leather which passes down to a small windlass at *h*, used for raising or lowering the magnet; *i*, a copper bar, about 1 inch square, used to check the vibration of the magnet.

The magnet is a bar 2 feet long, 1½ inch broad, and about a quarter of an inch thick. It is of hard steel throughout.

Upon the cross-bars of the stand rests a double rectangular box, covered with gilt paper on the interior and exterior sides of both, one box being completely enclosed within the other. Within these the magnet vibrates freely.

At the distance of eight feet from the centre of the magnet is placed a theodolite, on a stone pier firmly fixed in the ground, and unconnected with the floor. The telescope of the theodolite is generally directed to the cross of cobwebs carried

by the magnet, which therefore moves as the magnet moves; a record of the apparent position of the cross, as seen in the

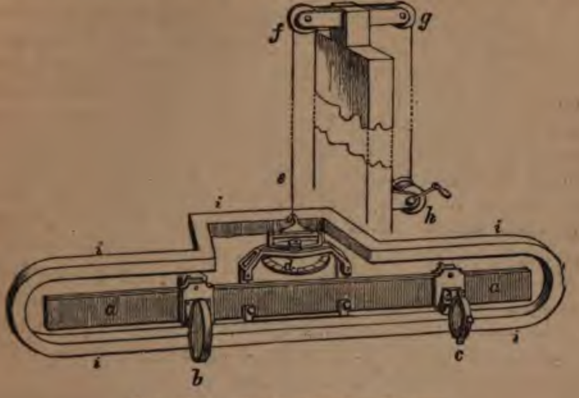


Fig. 357.—The Declination Magnet.

telescope, will denote the position of the magnet with respect to the reading of the divided limb of the theodolite.

The theodolite-telescope can be turned so as to observe stars as they pass the north astronomical meridian through an opening in the roof. The difference between the reading of the theodolite, when directed to the south astronomical meridian, and its reading when the telescope is directed to the magnet, when corrected for disturbing causes, to be alluded to presently, is the magnetic declination, or the inclination of the magnet to the astronomical meridian, or, popularly, the variation of the compass. Great care has been bestowed upon determining the effects of each pair of magnets upon the third, and this effect is allowed for in the reductions; also the effect of the mean-time clock has been found: experiments have been made upon every thing near the magnets that could possibly influence them; such as the fire-grate in the ante-room, the bars of which are of iron, the iron about the electrometer-pole, &c., and when such influence is sensible it is taken into account in the reductions. This applies to every magnet in the Observatory.

The amount of the magnetic declination is found to be dif-

ferent at different times of the day, being greatest at about 1 P.M.; the north end of the magnet then moves towards the east, or the magnet approaches the astronomical meridian, till six or eight in the evening, the declination at the latter time being about ten minutes of a degree less than it was at the former time; the north end then recedes from the astronomical meridian till about two o'clock in the morning, and moves in the contrary direction till four o'clock, at which time it again changes the direction of its motion, and approaches the astronomical meridian till six or eight in the morning, when it again begins to move from the meridian. Thus the diurnal movement consists of a double approach to, and a double receding from, the astronomical meridian every day.

The mean diurnal change in the position of the magnet is about 14 minutes of a degree in the summer, and about 2 minutes less in the winter; but there are some days on which the whole arc may not be more than three minutes, and on others it may be more than a degree.

Fig. 358 is a representation of the *horizontal-force magnet*, viewed from a position south-west of it: *a* is the magnet; *b*, the mirror carried by the magnet, with the screws for adjustment; *c*, the torsion-circle; *d*, a system of five pairs of small pulleys; *e*, *e*, two halves of a skein of silk, which rise from the upper pair of pulleys to another pair of pulleys, 7 feet 9 inches above them, *f*; then over the pulleys at *g*, and so down and over a single large pulley, not shown in the drawing, whose axis is attached to a string that passes down to the windlass, the handle of which is represented at *h*; *i*, a copper bar encircling the whole magnet.

The magnet is of the same dimensions as the declination-magnet. It is supported by a broad tripod stand, resting on the ground, and not touching the floor. The stand rises 11 feet 5 inches above the floor, carrying at the top the pulleys for the suspension of the magnet, represented at *f* and *g*. The magnet vibrates in a double rectangular box, similar to that in which the declination-magnet vibrates. Part of the south side of the box is of plate glass.

At the distance of 8 feet 5 inches due south of the magnet is fixed to the wall of the east arm a scale of numbers; these numbers are seen with a fixed telescope directed to the mirror which the magnet carries. The telescope is fixed to a wooden

tripod stand, whose feet pass through the floor without touching it, and are firmly connected with piles driven into the ground.

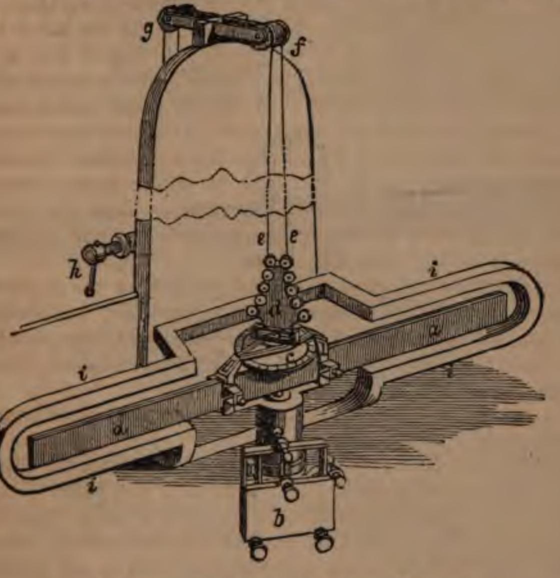


Fig. 358.—The Horizontal-Force Magnet.

Its position is such, that an observer, sitting in a chair, can, by turning his head, look into the telescope of any one of the three magnets. This magnet is placed very nearly transverse to the magnetic meridian, and held there by the directive power of the two halves of the suspending skein *e*, *e*. The magnet is constantly endeavouring to move to the magnetic meridian, or parallel to the declination-magnet; and as the magnetic power increases or diminishes, the two threads of the suspending skein become more or less twisted, and different numbers of the scale are seen in the observing telescope, from which the variations of the force are determined. It is found that at about noon the magnetic force is least, as the magnet is the least drawn towards the north. It then moves toward the north till about 6 P.M; it remains nearly stationary till

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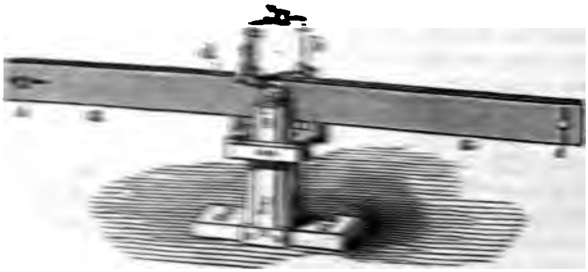

Fig. [illegible].—The Vertical-Force Magnet.

[illegible] the two other magnets, in which the [illegible] the deviation of the [illegible] magnet in its position [illegible] in which the [illegible]

The magnet [illegible] same dimensions as the other two magnets [illegible] connected with [illegible] and rests on the ground [illegible] as nearly as possible, symmetrical with that [illegible] magnet in the opposite arm. The [illegible] similar [illegible] to those in which the other magnets [illegible] in the block of wood [illegible] the magnet vibrates freely up and down [illegible] the south side of the box is of plate-glass. [illegible] symmetrical in form and position with that [illegible] carrying the telescope of the horizontal-force magnet) carries a telescope, which, being directed towards the mirror, the observer sees in the telescope the numbers on the scale, which is vertical and fixed to the stand carrying the telescope. As the magnet inclines more or less to the horizon, the numbers on the scale, as seen through the telescope, increase or

diminish, and from this the variations of the vertical force are determined. It is found that at two o'clock in the morning the marked end of this magnet is less drawn downwards, and at four P.M. it is more drawn down than at any other time in the day.

The cut (fig. 360) represents the apparatus at the top of another instrument, called the *electrical pole*: *a*, a lantern at the summit (the lamp is always burning); *b*, the copper tube on which the lantern slides; *c*, dotted lines which represent a cone of glass, on which the copper tube carrying the umbrella *h* above is fixed, to protect the glass from rain, &c.; *d*, a wooden apparatus enclosing the lower part of the cone of glass. The lower part of the glass is hollowed out and lined with copper, immediately under which is placed a lamp, represented in the drawing at *e*, which is constantly kept burning for the purpose of heating the copper, and thus keeping the glass dry; *f* is a wire communicating with the electrical instruments in the ante-room; *g*, *g* are iron rods upon which the whole apparatus slides up and down.

The electrical apparatus, as it appears in the window of the ante-room, is represented in the next cut (fig. 361). *a*, the hook, a part of the connexion of the conducting wire with the apparatus; *b*, an umbrella to cover the opening in the upper part of the window, through which an upright rod passes, carrying the apparatus below; *c*, *c*, a double cone of glass supported by the upper part of the window by brackets at each end; *d*, *d*, lamps placed nearly at the end of each cone of glass, for the purpose of keeping the glass dry; *e*, a collar encircling the glass, and by means of the vertical rod *f* supporting the hollow copper tube *g*, carrying the several electrical rods, which can be moved upwards and downwards, and by this means brought into connexion with the electrical instruments immediately underneath, and can be fixed by screws in any position; *h*, a Bohnenburger's single-leaf pendent gold-leaf electroscope, and a pair of Zamboni's dry electric piles (this instrument is extremely sensible to slight changes of electrical excitation, and indicates in a marked manner not only the presence but the kind of electricity); *i*, a galvanometer, for exhibiting currents of electricity in the atmosphere; *k*, an instrument to measure the lengths of the electrical sparks; *l*, another dry-pile apparatus similar to *h*,

but less sensitive; m, m, straw electrometers, much used in

Fig. 360.—The Electric Light Apparatus, &c.

observing electrical changes in the atmosphere. These last

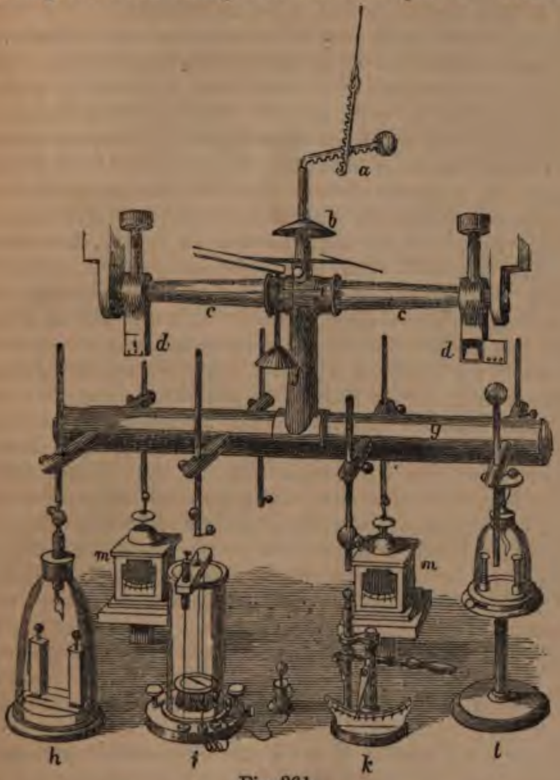

Fig. 361.

are furnished with graduated arcs, to estimate the amount of the electric force.

In order to collect the electricity, a lamp is constantly kept burning in the lantern *a*, fig. 360. The glass cone below it being kept dry is a non-conductor; therefore, the only way that the electricity can escape is down the wire *f*, and so to the several instruments *h*, *i*, *k*, *l*, *m* and *m*. The whole apparatus indicates changes in the atmospheric electricity preceding changes in the weather.

Electric sparks are frequently obtained. The colour of the spark is blue, and frequently violet and purple.

The method hitherto adopted for observing the indication of these instruments has been that of viewing, through a fixed telescope, the divisions of a fixed scale reflected by a plane mirror attached to each magnet. But by this system of observation a very imperfect knowledge of the nature of magnetic changes has been obtained; and as it has been deemed necessary, in magnetic observatories, that the observations of the various instruments should be made at intervals of at furthest two hours, by night as well as by day, a laborious duty has devolved upon the assistants; some means of enabling these instruments to record their own changes was long an acknowledged desideratum. With the aid of photography this desired object has been attained, and an ingenious instrument for applying which, constructed by Mr. Brooke, received a medal at the Exhibition of 1851.

By Mr. Brooke's self-registering apparatus an uninterrupted and unerring record of all magnetic changes is now maintained at the Greenwich Observatory. These results could not have been arrived at by personal observation; for even if every telescope were constantly watched by the eye of an assistant (which would require a very numerous staff), the results would be liable to errors of observation; and occasionally the magnetic variations are too rapid and transient to be continuously recorded by any observer. We may further remark, that since the employment of this apparatus at Greenwich, the number of assistants in the magnetic department has been reduced, and the fatigue of night duty has been dispensed with entirely.

Magnetic registration is one of the most useful applications hitherto made of the beautiful art of photography. The method applied to each of the magnetic instruments may be thus described:—A concave metallic mirror three inches in diameter being attached to each by a frame comprising all requisite adjustments, the rays of light from a lamp or gas burner, placed at a distance of about two feet from the mirror, pass through a small aperture in a metallic plate, and fall on the mirror, whence they are reflected to a focus at a certain distance. The source of light being fixed, it is clear that the movements of the focal point of light will correspond with

those of the magnet. A cylinder covered with photographic paper is so placed that the point of light may fall on it. The cylinder is carried round on its axis by clock-work, and, by the combined movements of the point of light and of the cylinder, the magnetic curve is self-traced upon the sensitive paper. The photographic process has also been applied to the barometer, and to the wet and dry bulb thermometers; but the mode of application is different from the preceding, the light not being reflected from a mirror.

As the preparation of the sensitive paper used in these instruments differs somewhat from that adopted in ordinary photographic processes, it may not be inappropriate to describe it. The paper is first washed with a solution of four grains of isinglass, eight of iodide, and twelve of bromide of potassium, in one fluid ounce of distilled water, and dried quickly by the fire; a considerable quantity of paper may be thus prepared at once. Previously to being placed on the cylinder, the paper is washed over with a solution of fifty grains of nitrate of silver to one ounce of water, which communicates to it the requisite degree of sensibility. After having been in action for twenty-four hours, the paper is removed from the cylinder, and the impression developed with a warm solution of twenty grains of gallic acid to one ounce of water, with a small addition of the ordinary commercial strong acetic acid: this is subsequently fixed in the usual way with hyposulphite of soda.

The principle of the photographic part of the apparatus is shown in the annexed cut (fig. 362), in which *a* represents a part of a bar magnet; *b* a concave mirror, resting in a stirrup firmly attached to the suspension apparatus, the whole being supported by a single thread; *e* a blackened glass cylinder, wrapped round with photographic paper; *d* a plano-convex lens; *c* a lamp placed a little out of the line which joins the centres of the cylinder and magnet. In operation a pencil of light passes from *c* through a very narrow slit or aperture, diverges and spreads over the mirror *b*, from which it is reflected, and diverges to the lens *d*, and is condensed into a well-defined spot of light at the surface of the paper. The action of this spot upon the photographic paper is to leave a trace, which is, however, imperceptible, until removed and developed in the manner pointed out.

As the whole of the suspension apparatus is firmly fixed together, the mirror partakes of every movement of the magnet,

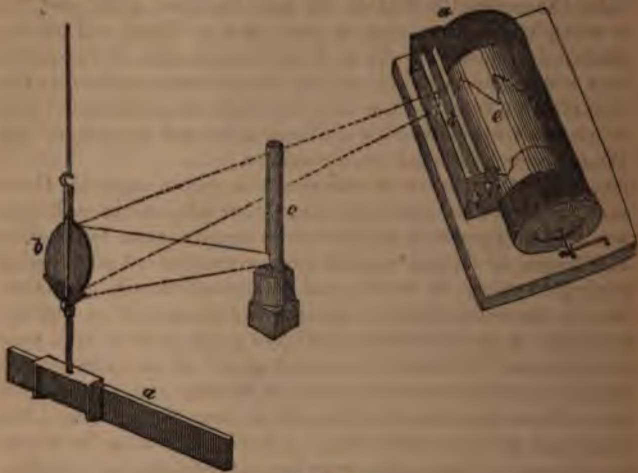

Fig. 362.

and reflecting the spot of light to different parts of the paper, according to the communicated movements, causes the photographic action created by the spot to become a record of the movements of the magnet with which it is identified.

The undulations in the trace, when developed, are in exact accordance with the deflection of the magnet to the right and left; a period of rest, during which time the spot remains stationary, being indicated by an undeviating line, the continuity of which remains unbroken, as the cylinder is placed in gear with a chronometer by means of the winch-iron at the end, resting in the hand of the chronometer, forked for its reception, which revolves once in twelve hours.

When we consider that our health, and even life, depend upon the weather, that storms arise and wreck our vessels, that heavy rains inundate our lands and damage or destroy our crops, that in an island striving to make the most of the soil, and vying with the world in its manufactories, and in a population far advanced in scientific knowledge in all its branches, and studying the best means of preserving life and health, and

of attaining domestic comforts, it is not to be wondered at that meteorology is now attracting considerable attention. Probably the reason this study has been hitherto much neglected is owing to the fact, that weather changes being variable and unaccountable, we are apt to think it impossible to find out the laws which govern them, and perhaps even to doubt the existence of such laws. That laws do exist, as powerful as those which connect our earth with the sun, there cannot be a doubt. Were there no laws, we should be parched with thirst, or deluged with rain—scorched by an overpowering heat of the sun, or frozen to death by excessive frost. Storms of wind would tear up our largest trees and hurl down our noblest buildings; or the air would remain immoveable and stagnant, ceasing to carry off the poisonous exhalations from our towns. As it is, however, we have a certain range of temperature and pressure; rain will always fall to a known extent, yet never exceed a certain limit; the air can never be very long at rest, and the velocity cannot extend beyond an ascertainable pressure. Even the clouds, of which nothing can be said to be more changeable, obey a law, by which the earth is shielded in a greater or less degree from our winter's cold and summer's heat. Thus, in summer, the greatest amount of cloud occurs in the afternoon, and the least at night; whilst in winter the reverse takes place.

Electro-Magnetism.

Philosophers laboured long in the endeavour to trace the relations of electricity, galvanism, and magnetism to each other, and to find out the law by which polarity was given to steel bars by means of electricity; but nothing decisive on this subject was discovered until the year 1819, when Professor Œrsted, of Copenhagen, announced a series of investigations that have formed the foundation of the science of electro-magnetism. Œrsted stated that if a magnetic needle, free to move, were brought parallel to a wire conveying electricity, it would leave its natural position and take up a new one, dependent on the position of the wire and needle to each other. If the needle be placed horizontally under the wire, the pole of the needle nearest the negative end of the battery will move westward; but if the needle be placed above the wire, the same pole will move eastward. If the needle be placed in

the same horizontal plane as the wire, no motion takes place in that plane, but it inclines to a vertical action: when the wire is to the west of the needle, the pole nearest the negative side of the battery is depressed, but when it is on the eastern side it is elevated. From these phenomena Œrsted concluded that the magnetic action of the electricity moved in a circular manner round the conducting object. A wire that connects the two extremities of a voltaic battery was termed by Œrsted the conjunctive wire. By bringing the north pole of a magnetic needle below and at right angles to the platinum wire, it will be repelled, but if above it attraction takes place. Reverse the poles of the needle, and the results will be reversed. Upon this deflection of the needle by the voltaic current depends the working of the modern electric telegraph.

Professor Œrsted laid down the following formula:—"The pole *above* which the negative electricity enters is turned to the west; the pole *under* which it enters to the east."

Faraday constructed a delicate apparatus (fig. 363) which consisted of a vessel nearly full of mercury; in the centre of the bottom of the cup a copper wire *a b* was inserted, a cylindrical magnet *e f* was fastened by a thread to the wire, and the north pole of the magnet only projected above the mercury; *c d*, a conductor, was inserted in the mercury exactly over *a*. The wires of a battery were then attached, and as the current passed through the mercury from one wire to another, the magnet rotated about it. If the positive current descended, the rotation was in the direction from east through south to west; but if the current was made to ascend, then the direction of the motion was reversed.

Fig. 363.

The ingenious experiments of Ampère in France, and Davy in England, at length showed that the conjunctive wire became possessed of all the properties of a magnet, and that pieces of steel placed at right angles to an electric current might be magnetized to a degree correspondent to the amount of electricity passed round them.

Arago, under the direction of Ampère, formed a helix of wire, having at each end a small cup of mercury, and on

placing in the axis a needle, it became instantly magnetized (fig. 364).

Fig. 364.

Fig. 365.

Thus by an electric current we may produce magnetism. If we take a piece of soft iron somewhat in the shape of a horseshoe, then coil round it cotton or silk-covered copper wire, the ends of which are united to the extremities of a voltaic battery, we create an *electro-magnet* of enormous power.

These magnets are temporary, their power only lasting while the electrical current is passing through the wire. In this respect soft iron differs from steel, as the latter acquires magnetism more slowly, and retains it after the exciting cause has ceased. The cotton or silk wound round the copper wire is to insulate it throughout its course. A magnet has been formed on this principle capable of sustaining upwards of one ton six cwt., while the magnet and its coil were not more than 35 lbs. weight. A magnet exhibited in London, at an eighth of an inch distance, attracted iron with a force of 1344 lbs., and required more than two tons force to separate it when in contact.

One peculiarity attends the electro-magnet, which is, that although it is capable of sustaining this immense weight, its attractive power extends but a short distance.

Electro-Motion.

The discovery being made that magnets, almos illimitable in power, could thus easily be constructed, attention naturally was given to their application as a motive power. The advantages of such a power, in certain respects, over steam were self-evident, from its noiseless action, portability, safety and con-

trollability. Professor Jacobi, assisted by the Russian government, succeeded in propelling a boat upon the Neva at a rate surpassing that obtained in the first attempts at steam navigation. In his experiments in 1839 he had a boat 28 feet in length and 7½ in width, which drew about 3 feet water. Ten persons were on board, and the paddles were moved by an engine worked by a Grove's battery of 64 pairs, each platinum plate having 36 square inches of surface. The speed attained was four miles an hour. The Russian philosopher has applied the same power to various machines, but not yet with decided success.

Mr. Robert Davidson attempted in 1842 its application to railway locomotion, and succeeded in propelling a carriage weighing five tons, at the rate of four miles an hour on the Edinburgh and Glasgow Railway.

Mr. Davenport and Professor Page, in America, have made several attempts to accomplish the motion of machinery by electro-magnetism in lieu of steam. The latter is said to have constructed engines of considerable power. He also worked a printing-machine of four horse-power, and a trip-hammer which he controlled at a slow or rapid speed with the utmost facility.

An ingenious Danish gentleman, named Hjorth, took out patent in 1849 for an electro-magnetic motive engine. It was of ten horse-power, and one of the electro-magnets was capable of supporting 5000 lbs. weight; at a distance of one-eighth of an inch its attractive force was equal to 1500 lbs.

Although many scientific persons maintain the impossibility of its superseding steam, we would advise some caution in such assertions; for it must be remembered that when it was first suggested to light towns with gas, the greatest chemist of the time, Davy, recommended the company as an easier method of accomplishing their object, to cut a slice off the moon. As to oceanic steam navigation, Dr. Lardner proved to the British Association, most satisfactorily, its utter impracticability in a commercial point of view. Stephenson was laughed at by a learned Quarterly Reviewer, when he ventured to state that he could move carriages on railways, by locomotive power, at a rate of twenty miles an hour. Yet all these objects are fully attained.

The motive power of electro-magnetism has been most suc-

cessfully applied to the mechanism of time-keepers. Clocks are now found in action at the principal railway stations, chronometer-makers' shops, and telegraph offices in the kingdom; many private establishments have adopted them, and find they will go better than the ordinary time-pieces, that they cost but little, and their regularity can be thoroughly depended upon. Greenwich time is notified in London by the electric ball-apparatus in the Strand and Cornhill.

Magneto-Electric Machine.

We have seen that magnetism may be produced by electricity. The converse also may occur, and magnetism produce electricity.

Faraday was the first person who demonstrated that from ordinary magnets a continuous stream of electricity could be produced. In a variety of ingenious methods he rendered this plain. He had a curved bar of soft iron, around which he wound 500 feet of copper wire, leaving the ends bare; the ends of the wires he connected with a delicate galvanometer; on bringing the ends of the soft iron in contact with the ends of the magnet, he obtained the usual indications of the presence of electricity; and on breaking contact the needle was again deflected, but in the opposite direction. M. Hipolyte Pixii, of Paris, followed up the discovery of Faraday. With a coil of 3000 feet of wire round a curved bar of soft iron, which bar he placed very near the ends of the permanent magnet,

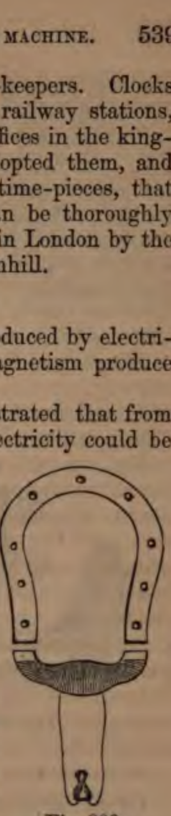

Fig. 366.

and causing the magnet to revolve round very rapidly, making and breaking contact every time the poles passed the ends of the bar, he produced a continuous and rapid succession of brilliant sparks; this was the first magneto-electric machine. In 1833 and 1835 this instrument was improved by Mr. Saxton, who, instead of causing the magnet to revolve, had a double *armature* which turned round. By this magneto-electric machine, represented in the accompanying figure (367), a continuous stream of electricity may be produced of sufficient force to give violent shocks, to melt metals, and to exhibit most of the phenomena of a powerful voltaic battery. The

principal parts of the instrument consist of a strong compound permanent steel magnet $a\,b$; and two combined pieces of soft iron $c\,d$ covered with helices of copper wire, and fixed on an axis, so as to rotate in close proximity to the surfaces of the permanent magnet. A multiplying-wheel e gives rapid rotary motion to the soft iron armature, the ends of the wire round which are so arranged that contact is made and broken at each revolution; and at every break of contact a current of electricity is evolved.

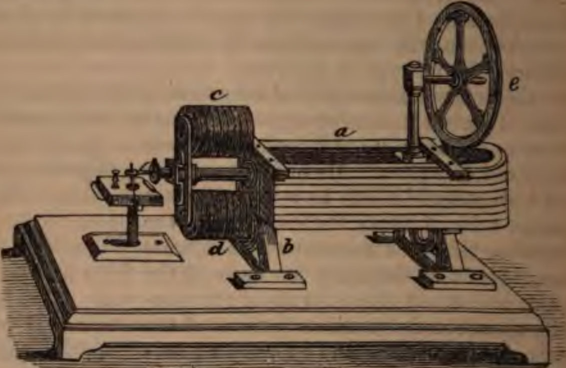

Fig. 367.—Sexton's Magneto-electric Machine.

The Electric Telegraph.

Of all the recent achievements of science the Electro-Magnetic Telegraph is the most wonderful. By it, space is annihilated and time beaten—light is out-distanced in the swiftness of its flight—news speeds along wires buried in the earth, sunk in the ocean, or stretched on poles, telling of the fall of empires or the flight of kings, the price of stocks, of births and bankruptcies, arrivals and departures, accidents and wrecks, crops, robberies, murders, and markets. Friends hundreds of miles distant may converse as if in the same apartment; may print what they wish announced; may write, and by their hand prove their identity. Journeys are saved, feelings are soothed, anxiety is banished, and safety promoted to person and property, by the magic of this extraordinary invention.

In 1748 Dr. Watson, Bishop of Llandaff, in company with other scientific persons from Shooter's Hill, laid down a wire on land and through water more than four miles in length, and through this passed the electric current in a space of time that could not be appreciated; hence he conceived the application of such means to a system of conveying signals. The Bishop's experiments were repeated on the continent, and in one instance through a circuit of twenty-six miles. In 1787, M. Lamond attempted to practise it in France, but his plan never became popular. Mr. Ronalds of Hammersmith, in 1816, exhibited a telegraph with a wire eight miles in length, worked by electric clocks; and M. Sömmerring invented a very ingenious contrivance for telegraphic purposes.

All these inventions were truly electric telegraphs. The current of voltaic electricity was made to act on a signaling machine resembling the pith-ball electrometer, the divergence of the pith-balls being the sign. This system required batteries of high power; it was liable to fallacy, and otherwise inconvenient.

Probably this boon to our time—the power of almost instantaneous correspondence—would never have been practically granted, had it not been for the great discovery of Œrsted, already mentioned. He showed that the magnetic needle could be deflected by passing a voltaic current round it. He showed also that by similar means a rod of soft iron could be converted into a magnet of considerable power. Upon these two discoveries, but especially the first, the construction of all modern or *magnetic telegraphs* depends; and when they were made known, the invention of a working machine became comparatively an easy thing, a matter that the skilful mechanician could solve without great difficulty.

A battery at one place—an insulated wire stretching to another place, 50, 100, 1000 miles off—at that place a magnetic needle (in a box) round which this wire is made to pass before its final immersion in the earth—another needle on a dial plate, which moves or beats in correspondence with the needle within, by these motions or beats making certain signals or letters—such is the common magnetic telegraph.

The conducting wire may be hung upon poles, carried in tubes underground, covered with gutta percha, and twisted with others into a rope. This rope may be swung over wires

sunk at the bottom of seas, buried beneath fathomless oceans, where the mile-deep water is always still.

Nothing but engineering difficulties, soon to be overcome, impedes the universality of the mighty system. Already Europe, America, India are covered with wires. Already by the submarine telegraphs we are placed in communication with all Europe and with Ireland. The chain that is to unite us with America only waits the laying down, and another through Turkey, and down the Euphrates to India, is preparing. Australia only is left. We doubt not that the present generation will see the day when a scheme of centralization such as legislators never dreamed of may become a sober possibility—when India and Australia and Canada may be ruled as well from London as from Calcutta, or Melbourne, or Quebec; and villages in Africa, but five miles asunder, may be practically further apart than we from our antipodes.

Dr. Ritchie and Davy were the first, after the discoveries of Œrsted and Ampère, who exerted themselves to bring the invention to a practical state; but it was not until 1837 that a successful method was exhibited by Mr. Alexander, of Edinburgh, before the Society of Arts of that capital, and for which he took out a patent in the same year. It was in the form of a chest, and consisted of thirty-one separate wires, for the alphabet, stops, and signals. A series of troughs of mercury communicated with a voltaic battery; a series of keys like those of a pianoforte were provided, having a wire run underneath each, by which the communication with the trough of mercury could be made; these being pressed down completed the circuit; each key communicated with a magnetic needle, on which was placed a screen concealing a letter; so that on the depression of a key the current passed to the according needle, which being deflected the letter was uncovered; as soon as the contact ceased, the letter was again hidden.

Many improvements and inventions followed; and at last Professor Wheatstone and W. Fothergill Cooke brought the matter to such perfection, as to cause it to be adopted in connexion with the railway system of the kingdom, and to become a valuable addition to individual and national happiness.

We will now shortly describe the arrangements adopted in this, which is one of the best known and at one time the most widely used telegraph instrument, premising that many different ma-

chines are in use on different lines, consisting of much complex mechanism, though depending for their action on simple principles. In the great system of subterranean wire now laid down by the Electric Telegraph Company throughout the kingdom, peculiar difficulty was at first experienced from a recoil current which followed the current on which the message depended. This has had to be overcome by some instruments of a special nature, used as supplementary to the telegraph machine.

The batteries used for the purposes of the telegraph are the same in principle, but a little different in detail, with those we have already described. They consist of a strong wooden water-tight trough, with partitions of slate; the zinc and copper plates are connected by slips of copper to which they are soldered, and which slips support them on the slates. The cells are filled with fine sand, saturated with one part of sulphuric acid to fifteen of water, and according to the distance is the number of cells required. The zinc plates are first amalgamated by leaving them for a short time in a solution of bichloride of mercury, by which they become coated with mercury and more durable. The two wires from the opposite ends of the trough are then ready for use, and are attached to the telegraph. As two wires only are used, without return wires to complete the circuit, a large piece of metal is buried in the earth, to which a branch wire from the telegraph instrument is attached, or it is fastened to the water or gas pipes of towns.

The earth then completes the circuit, rendering a return wire unnecessary. It has even been found that the earth has some further action, not quite understood, by means of which it increases the intensity of the current passing through the wires.

The first act on commencing operations at the electric telegraph instrument from either station is that of ringing a bell, which is performed by what is termed a striking apparatus placed on the top of the instrument, seen in fig. 368, where the attendant is present. This apparatus consists of an armature *c c* formed of soft iron with silk-covered fine copper wire, connected together. As soon as the current of electricity passes into them, the iron bar in the centre of each becomes a magnet. At a little distance from them at one end is a piece of soft iron *d*; this is attracted to the magnets, and as it is

attached to the bent lever e, it moves the lower end, to which

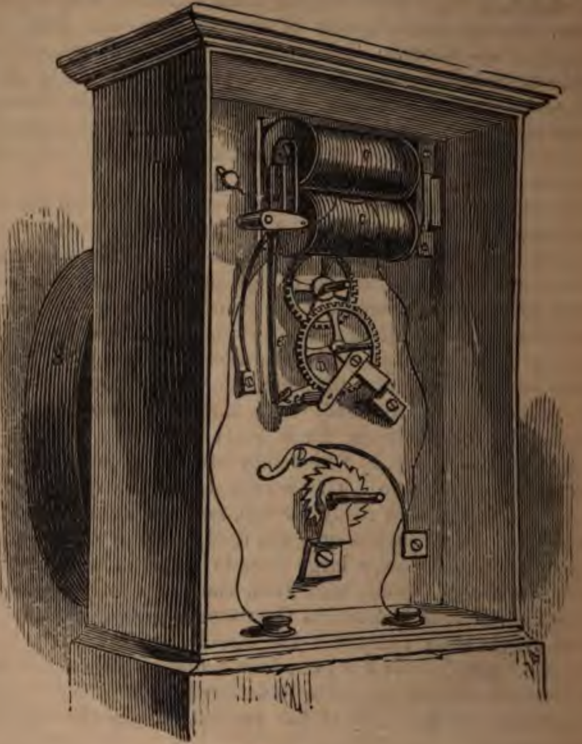

Fig. 368.

there is a catch backward, by which motion the pin f is released. The wheels being at liberty, and acted upon by a main spring, they whirl round and give motion to a hammer that strikes the bell g. On the left of e there is a slight spring that reacts on the lever and restores it to its position when the attraction of the electro-magnet ceases, and causes the catch again to hold the pin f.

As soon as the attendant arrives at the dial to which his attention is called, his first care is to stop the noise of the bell.

that keeps ringing until attended to. On the left-hand side of the dial-box (fig. 368) there is a brass handle, by turning which the current is made to pass to the wires of the dial instead of proceeding on to the clock; then the attendant replies with a signal to "go on" or "wait" (see fig. 370), which will be explained presently.

As soon as the voltaic force is applied at one end of the

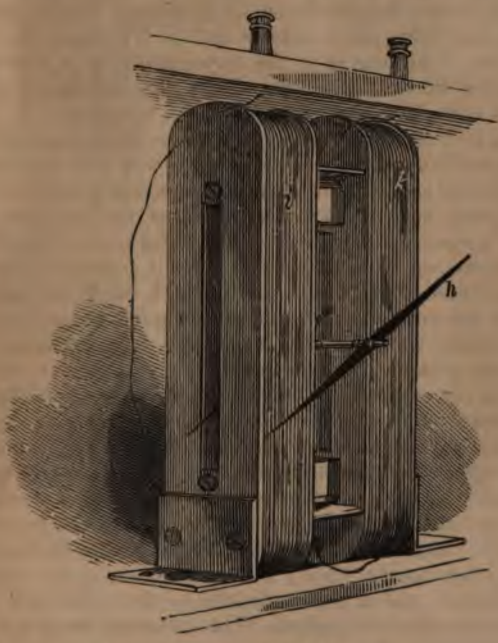

Fig. 369.—The Coiled Magnets.

wire, it is sensibly felt at the other end; and according to the direction in which it arrives at the instrument, the magnetic needle is moved to the right or to the left. The portion of the apparatus which indicates this is termed the *telegraph galvanometer*.

Two magnetic coils are made, consisting of very fine silk-

covered wire $i\,k$ (fig. 369). These are placed vertically, and within is a needle having its north end downwards, communicating and acting upon another needle h, which is outside the dial or index-plate.

The handles seen in fig. 369 turn a wheel or drum, by which the circuit is made instantly either in one direction or the other. This appears by the deflection of the needles at both ends of the line at one and the same time. If the attendant turns the handle so as to send a positive current through the wire, the needle is deflected towards the right hand; and if he turn it in the opposite direction, the needle is deflected towards the left. Thus the movement of the needle is entirely at the command of the operator.

When we watch the working of a telegraph, and see the little delicate needles rapidly move slightly to one side and then to the other, and are told this is caused more than a hundred miles distant, and hear the attendant deliver to the clerk some lengthy message of private or public import—we wonder how such motions can be so interpreted; yet it is actually the most easily acquired alphabet known by which words are spelt.

When the needle is made to go to the left twice, the letter *a* is meant; when thrice, the letter *b* is intended; and when the pointer goes first to the right, then to the left, the letter *c* is expressed. On the pointer moving to the cross it signifies "stop"—the word is complete; but if the attendant receiving the message does not understand, he makes a return signal of once to the cross, and the other party repeats the word. As each word is received the attendant acknowledges he understands it by pointing once to the letter E on the dial. The letter D is signified by the needle first going to the left, then to the right; E is one motion to the right; F two motions; and G three motions to the right, and so on through the whole alphabet. The technical term for these motions is *beat*. For "yes" one beat is made to E; once to E with both needles to the right signifies "wait," and both needles to the left signify "go on."

In the *electric printing-telegraph* inked types are brought into contact with the paper by the force of an electro-magnet. The perfection and rapidity of execution are surprising, and on the lines where they are employed have been perfectly successful.

The *copying electric telegraph* (fig. 371), invented by Mr.

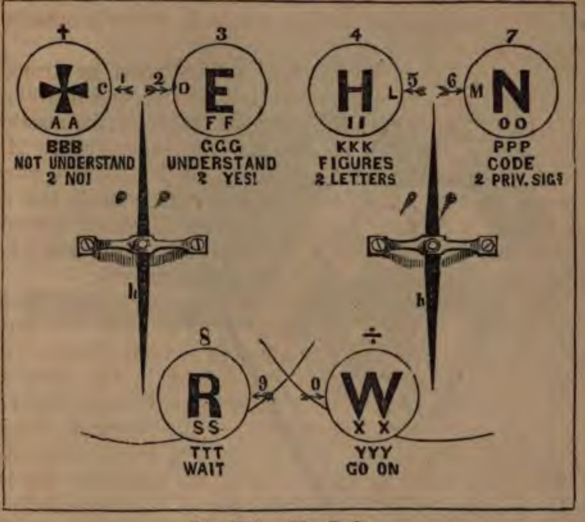

Fig. 370.—The Index.

F. C. Bakewell, is extremely simple. The messages to be transmitted are written on tinfoil with sealing-wax varnish, and are then applied to a cylinder on the transmitting instrument. A metal style connected with the voltaic battery presses lightly on the writing; and as the cylinder revolves by the influence of a weight, the metal point is carried by a fine screw, on which it traverses, from the top to the bottom of the lines of writing. By this arrangement the style passes several times over each, but in different parts, of the letters. The receiving instrument resembles the transmitting one; but on the cylinder of that instrument paper moistened with a solution of prussiate of potass and diluted muriatic acid is applied, and the metal style consists of a piece of fine steel wire. The electric current from the positive pole of the voltaic battery is conducted by a communicating wire to the steel point, and passes through the paper to complete the voltaic circuit. The action of the electricity, when the current is passing, decomposes the muriatic acid, and the steel combining with the chlorine of the

acid, a deposition of iron takes place on the paper, which is

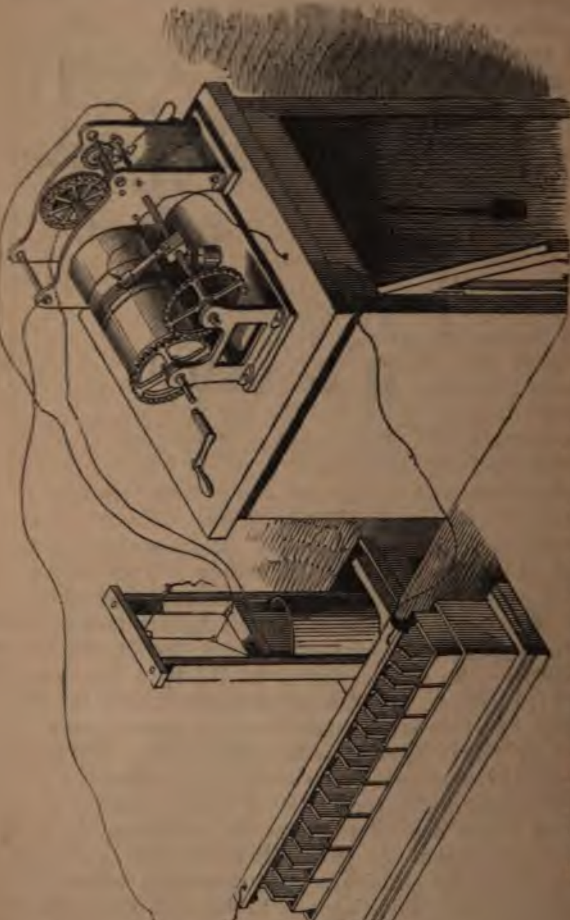

Fig. 371.—Bakewell's Copying Electric Telegraph, in connexion with the Galvanic Trough and Magnetic Regulator.

instantly converted into prussian blue by the prussiate of

potass. By this arrangement, therefore, the steel point of the receiving cylinder draws a succession of blue lines spirally over the paper when the electricity is passing through it; but when the electric current is interrupted by the varnish writing, over which the point of the transmitting cylinder is continually passing, the electric current is momentarily interrupted, and the marking ceases. The small intervals caused by the cessation of marking, where the varnish interposes, produces an exact copy of the written message on the paper, the letters appearing nearly white, on a ground composed of blue lines drawn very closely together.

It is essential to the success of the process that the two separate instruments should rotate exactly together; otherwise the receiving paper would present a confusion of marks, instead of legible writing, for the different parts of each letter would be marked irregularly. To produce a synchronous movement, Mr. Bakewell has contrived an electro-magnet regulator, by which means the effect may be produced at whatever distance the instruments may be apart.

The number of times absolutely requisite for the point to pass over each line of writing to make the copy legible is six; but when the screw is fine, and the writing large, the point passes over a greater number of times to bring out the forms of the whole letters.

The rapidity of the process depends on the smallness of the writing, and on the velocity of the revolving cylinders. The usual rate of working is one revolution in two seconds, and at that speed upwards of three hundred letters per minute can be transmitted. The practicability of this plan has been proved by the transmission of written messages between Brighton and London.

The advantages of this means of telegraphic communication are stated to be, entire freedom from error, as the messages transmitted are facsimiles of the original manuscripts; authentication of the communications by the transmission of copies of the handwriting, so that the signatures may be identified; increased rapidity, and consequent economy in the construction of telegraphic lines. The secrecy of correspondence would also be maintained, as the copying telegraph would afford peculiar facility for transmitting messages in cipher. As an additional means of secrecy, the messages may be transmitted

invisibly by moistening the paper with diluted muriatic acid alone; the writing being subsequently rendered visible by application of the prussiate of potass, the most delicate test of the presence of iron. The instantaneous appearance of the writing on an apparently blank piece of paper has a very curious and astonishing effect.

The accompanying illustration (fig. 372) shows the form in which the writing is produced at the distant station.

Fig. 372.

Professor Wheatstone's *universal telegraph* consists of two parts or instruments, the telegraph itself and another called the communicator. This telegraph, with all the apparatus for working it, is contained in a small box, much smaller than a lady's work-box. It has a handle like that of a barrel organ in front of it. On the upper surface there is a disc or clock face. This face, instead of having the hours marked round its circumference, has its thirty equal divisions on its outer edge marked by the letters of the alphabet, three stops, and a cross. The inner row has the nine digits and zero repeated twice. There is a hand like the hour-hand of the clock, which is made, by the mechanism hereafter to be described, to point to these letters, stops, or figures, at the will of the operator. Round this lettered disc are thirty keys, like those of an accordion, which can be depressed by the finger, one for each letter or sign. It is not much larger than an ordinary ship's chronometer. The communicator is something like a watch, a little larger, indeed, fixed on a stand in a convenient position for observing the dial: it rests on a small stand, which contains the apparatus for working an alarum bell. The face of the communicator has thirty divisions like the telegraph, with its double circle of letters and figures, and its moveable hand or index. It possesses very great advantages for private purposes; it needs no galvanic apparatus, with corrosive acids, nor does it require great skill in its preparation for use. There

are no fumes to be avoided, no trouble and risk in amalgamating plates. A simple coil apparatus and a magnet enclosed in the telegraph-box, do all the work of the electric-ariel, without risk of getting out of order or being deranged by a clumsy hand. Professor Wheatstone has discovered that, for moderate distances, say for twenty miles, his electric road only requires a copper wire about the thickness of an ordinary piece of cotton thread. Thirty such wires, each covered with a thin coating of india-rubber and linen, can be combined into a cable about the thickness of the little finger. Thus thirty private electric roads, perfectly insulated from each other, can be combined in one rope, not very much thicker than the wires now used for electric ways along the sides of our railways. This marks another great stride in telegraphy—the substitution of india-rubber for gutta percha as an insulator. Messrs. Silver and Co. have succeeded in demonstrating to the best telegraphists, that they can manufacture an india-rubber insulation for wires which shall make us independent of the constant failure of gutta percha as an insulator. The insulation of india-rubber is not only superior to gutta percha, but it resists the heat which would entirely melt the latter. We rejoice to see that Professor Wheatstone, who took such a distinguished position in the introduction of the telegraph, still keeps foremost in the race of telegraphic progress.

Mr. G. R. Smith's *comic electric telegraph* would, no doubt, prove an amusing and instructive toy, as it might be used to illustrate the principle of magnetic induction to children (fig. 373).

The action on the eyes and mouth of a comic face is produced by three bent iron bars within the figure, which are rendered magnetic by induction, and attract either of the features as above by means of armatures attached thereto. In addition to these novel signals, there are also the signs —, +, and ╲, by which not only all the letters of the alphabet are represented, but also the end of each word and sentence respectively properly indicated. These signals are shown by the elevation of shutters above the face. As each bar is capable of being separately magnetized, either of the signals can be shown at the will of the manipulator, by touching the corresponding key in front of the figure.

In concluding our volume, we must notice another triumph

achieved by a mind devoted to scientific investigation, and that is, the measurement of the duration of an electrical spark, and

Fig. 373.

of the rate of its passage along a wire, by Professor Wheatstone. By an ingeniously contrived apparatus he proved that the duration of the electric spark never exceeds a millionth part of a second, and that its velocity along wire is 288,000 miles in a second!

The learned philosopher, to illustrate that by this transient light an object in rapid motion might be viewed as if at rest,

had a circular disc divided into three compartments, on which he painted the three primitive colours, red, blue, and yellow. This he caused to revolve with great velocity, until the three colours appeared nearly white. He next darkened the room, and threw the light of an electric spark on the disc, when the spectators saw the colours as if the disc were at perfect rest.

Subsequently Mr. Fox Talbot produced an extremely sensitive prepared piece of photographic paper, and in June 1851, at the Royal Institution, placed it in a camera directed to a printed paper fixed on a wheel. The wheel was turned by a handle until the greatest velocity was attained that could be given to it. The camera was then opened, and a powerful electric battery was discharged in front of the wheel, illuminating it with a sudden flash of brilliant light. The paper was then taken out of the camera, and after applying the developing solution, a distinct image of the printed words was found beautifully impressed on the paper.

Thus, then, the last convulsive strain of a Flying Childers at a winning-post may be caught as it truly existed; or an express train, moving at a rate beyond muscular powers in an animal, or more speedy than the wings of the wind, may be transferred to a photographic plate as if it were at rest; for the utmost speed that can be given by man is but rest in comparison to the flight of electricity.

What, after this, is the most brilliant conception of the human mind in the region of imagination? True demonstrable poetry exists in the world of science.

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THE END.

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